BULLETIN

OF THE INSTITUTE OF METALS

VOLUME 2 DECEMBER 1954 PART 16

INSTITUTE NEWS

Spring Meeting, London, 29 March to 1 April 1955

The 1955 Spring Meeting will be held in London from Tuesday, 29 March to Friday, 1 April, inclusive. An outline of the programme, which will be published in detail in the January issue of the *Bulletin*, is given below:

Tuesday, 29 March

Location: The Royal Institution.

Evg. Annual May Lecture.

Wednesday, 30 March

Location: Church House, Westminster.

Morn. Annual General Meeting.
Presentation of Medals.
Presidential Address by Dr. MAURICE COOK.

Aft. Two simultaneous scientific sessions:
A.—*Theme:* Refractories for Low-Frequency Induction Furnaces.
B.—*Theme:* Fatigue.

Location: 4 Grosvenor Gardens, S.W.1.

Evg. Conversazione and Exhibition. (Tickets 4*s.*, including refreshments.)

Thursday, 31 March

Location: Church House, Westminster.

Morn. Two simultaneous scientific sessions:
A.—*Symposium:* "The Control of Quality in the Production of Wrought Non-Ferrous Metals and Alloys". Part III—"The Control of Quality in Heat-Treatment and Final Operations".
B.—*Theme:* The Constitution of Uranium Alloys.

Aft. Two simultaneous scientific sessions:
A.—*Symposium* continued.
B.—*Themes:* (i) Twinning.
(ii) Deformation and Fracture of Zinc.

Location: Grosvenor House, Park Lane.

Evg. Dinner and Dance (tickets, price 36*s.* each).

Friday, 1 April

All-day: Visits to works and laboratories.

1955 Autumn Meeting

The Council has accepted with gratitude an invitation from the Sheffield Local Section and the industries of South Yorkshire for the Institute to hold its next Autumn Meeting in Buxton, from Monday, 19, to Friday, 23 September, inclusive, with visits to works and laboratories in South Yorkshire.

Metallurgical Engineering Committee's Informal Discussion in Birmingham: Change of Subject to "The Treatment of Swarfs, Sawings, and Residues in the Non-Ferrous Metal Industries"

It has been decided NOT to proceed with an Informal Discussion on "Non-Metallic Die Materials", announced to be held at Birmingham on 16 February 1955. Members are, therefore, requested to amend their diaries and the printed programme of Institute, Local Section, and Associated Society meetings, accordingly.

Instead, under the auspices of the Metallurgical Engineering Committee, an all-day Informal Discussion on "The Treatment of Swarfs, Sawings, and Residues in the Non-Ferrous Metal Industries" will be held at the University, Edgbaston, Birmingham 15, on Wednesday, 16 February 1955, at 10.30 a.m. Visitors will be welcome, and no tickets are required.

Members and visitors may take lunch (price 5*s.* 6*d.*) in the University Refectory, provided that they give notice to the Secretary of the Institute *not later than Monday, 7 February*. Cash should accompany requests for lunch tickets.

Representation at Council Meetings

Captain (E.) W. F. B. Lane, D.S.C., R.N., has been nominated by the Lords Commissioners of the Admiralty as their representative in place of Rear Admiral (E.) H. J. B. Grylls, R.N.

Dr. L. Northcott has been appointed one of the two representatives of the Institution of Metallurgists at Council meetings, in place of Dr. Maurice Cook. Dr. E. G. West continues as the other representative.

Committee on the Application of Electricity to Industrial Processes

Dr. F. W. Haywood has been nominated as the Institute's representative on the Committee on the Application of Electricity to Industrial Processes (Institution of Electrical Engineers), in place of Mr. W. S. Gifford, who has resigned on grounds of ill-health.

1954 Students' Essay Competition

Members are reminded that entries for the 1954 Students' Essay Competition must reach the Secretary not later than 1 January 1955.

Particulars of the competition were printed in the October 1954 issue of the *Bulletin*; copies can be supplied to any persons interested, on application to the Secretary.

10-Year Index to "Metallurgical Abstracts", Volumes 1 to 10 (New Series), 1934–1943

Both the Subjects and the Names volumes of this Index are now available, bound in cloth. The price of the two volumes (they are not sold separately) is:

Members:	£4 4*s.* or $12.20 per set, post free
Non-Members:	£5 5*s.* or $15.15 „ „
Libraries:	£4 7*s.* 6*d.* or $12.70 per set, post free

These volumes are indispensable to all who make regular use of *Metallurgical Abstracts*, which is acknowledged to be the most complete and authoritative guide to the world's literature in the fields of general and non-ferrous metallurgy (excluding mining and extraction).

Members who have not yet ordered their copies of the Index should do so without delay.

The Secretary will be pleased to quote for sets of Volumes 1 to 10, with General Indexes, of *Metallurgical Abstracts* or of individual volumes. Some of the volumes are now in very short supply.

Election of Members

The following 29 Members and 37 Student Members were elected on 3 November 1954:

As Ordinary Members

ALLENDER, Peter John, Ph.D., B.A., F.R.A.S., Senior Research Metallurgist, B.S.A. Group Research Department, The Birmingham Small Arms Co., Ltd., Birmingham 11.

ARMAND, Marcel, Ing.civil Mines, Chef de Laboratoire, Société d'Electrochimie, d'Electrométallurgie et des Aciéries Electriques d'Ugine, Usine de Venthon, Albertville (Savoie), France.

ASH, Arthur, L.I.M., Metallurgist, Frederick Braby and Co., Ltd., Petershill Road, Glasgow, N.

BARNES, Richard Burcham, B.Sc., F.L.A., Chief Assistant Librarian, Central Library (The Manchester Public Libraries), St. Peter's Square, Manchester 2.

BODDEY, Ronald Frederick, B.Sc., A.R.I.C., Chief Chemist and Metallurgist, Foundry Services, Ltd., Long Acre, Birmingham 7.

CHIAPPA, Sergio, Dott.Chim., Manager, Fire and Electrolytic Copper Refinery, Società Metallurgica Italiana, Fornaci di Barga (Lucca), Italy.

CLARY, Philip Ebenezer, Chief Metallurgist, Ford Motor Co., Ltd., Dagenham, Essex.

COHEN, Philip, Ph.D., Technical Engineer, Aircraft Gas Turbine Development Department, Materials Laboratory, General Electric Company, Cincinnati 15, O., U.S.A.

EASH, John Trimble, B.S.Ch.E., M.S.E., Ph.D., Assistant Manager, Research Laboratory, International Nickel Company, Bayonne, N.J., U.S.A.

FINCH, Douglas Carver, B.Sc., Senior Metallurgist, Pressed Steel Co., Ltd., Cowley, Oxford.

FLEISSIG, Eduard A. S., Dipl.Ing., Chief Engineer of the Metal Department, Vollweiler and Company, Zürich 44, Switzerland.

FRAME, William M., B.S., Director, Research and Technology, National Tube Division, United States Steel Corporation, Pittsburgh 30, Pa., U.S.A.

GAVIOLI, Gaetano, Dirigente, Breda Istituto di Ricerche Scientifiche Applicate all' Industria S.p.A., Viale Sarca, 336, Milano, Italy.

GOSSMANN, Richard, Dr.Jur., Hüttendirektor, Fürstlich Hohenzollernsche Hüttenverwaltung, Laucherthal (Hohenzollern), Germany.

GUEISSAZ, Elie, Dipl.Ing., Production Manager, Fonderie Boillat S.A., Reconvilier, Switzerland.

HERBERT, David Brudenell, B.Sc., Assistant Metallurgist, Rockweld Ltd., Commerce Way, Croydon, Surrey.

JORGENSEN, Hemming Kristian, M.Sc., A.M.I.Mech.E., Managing Director, Impact Extrusions, Ltd., Browells Lane, Feltham, Middlesex.

MAROLDT, Ernest Jean Mathias, Technical Manager, Société Industrielle de l'Aluminium S.A., (SIDAL), Duffel, Belgium.

MIYASHITA, Kakunosuke, Dr.Eng., Works Manager, Wakamatsu Works, Hitachi Ltd., 8 chome, Ebisu-dori, Wakamatsu City, Kyushu, Japan.

MOORE, Leslie Charles, Steel Buyer, Fisher and Ludlow, Ltd., Erdington, Birmingham.

MORRIS, John Newton, L.I.M., Foundry Manager and Chief Metallurgist, McKechnie Brothers (S.A.) Pty., P.O. Box 382, Germiston, Transvaal, South Africa.

PARKER, Harry Lionel, A.R.I.C., Research Chemist (Metallurgy), Research Laboratory, Rolls-Royce, Ltd., Derby.

SCHÖNBERG, Nils Erik, Fil.Mag., Head of Laboratory for Hard Metal Research, Söderfors Bruk, Söderfors, Sweden.

SPERRYN, George Roland Neville, Joint Managing Director, Sperryn and Co., Ltd., Moorsom Street Works, Birmingham 6.

STRANG, Elmore Steele, Ch.E., Vice-President and General Manager, The New Haven Copper Company, Seymour, Conn., U.S.A.

STRATTON, William Bernard, Manager, Cametoid Ltd., Ajax, Ontario, Canada.

WAGMAN, Frederick Herbert, Ph.D., Director, University of Michigan General Library, Ann Arbor, Mich., U.S.A.

WARD, Raymond, B.S., Ph.D., Manager, Advance and Development Engineering, Industrial Heating Department, General Electric Company, Schenectady, N.Y., U.S.A.

WYATT, Oliver Hieron, M.A., Ph.D., G.I.Mech.E., Demonstrator, Engineering Department, University of Cambridge.

As Student Members

ALMETER, Frank Murray, B.Sc., Postgraduate Student, Department of Metallurgy, Royal School of Mines.

BAILEY, Norman John, Undergraduate, King's College, University of Durham, Newcastle-upon-Tyne.

BOWKER, Peter Howard, Undergraduate, King's College, University of Durham, Newcastle-upon-Tyne.

BRUMMITT, Roger Norman, Undergraduate, Queen's College, Cambridge.

CAMPBELL, William Henry, Undergraduate, Department of Metallurgy, University of Manchester.

CARVER, John Antony, Undergraduate, Department of Industrial Metallurgy, University of Birmingham.

CHOTINUCHIT, Phaotep, Undergraduate, King's College, University of Durham, Newcastle-upon-Tyne.

CLARIDGE, Maurice Arthur, Undergraduate, Department of Metallurgy, University of Birmingham.

DAVIES, Richard Glyn, Undergraduate, Department of Metallurgy, University of Birmingham.

DENNISON, Donald, Undergraduate, Department of Metallurgy, University of Manchester.

DIXON, Paul Richard, B.Met., Research Student, Department of Metallurgy, University of Sheffield.

GELLES, Stanley Harold, M.S., Graduate Student, Department of Metallurgy, Massachusetts Institute of Technology, Cambridge 39, Mass., U.S.A.

GIBSON, William Stewart, Undergraduate, Inorganic Chemistry Laboratory, University of Oxford.

GREGORY, Bernard, Student, College of Technology, Manchester.

GROVES, Ronald, Apprentice Engineering Metallurgist, Engine Division, The Bristol Aeroplane Co., Ltd., Filton, Bristol.

HARRIS, Bryan, Undergraduate, Department of Metallurgy, University of Birmingham.

HARVEY, John, B.Sc., Member of Experimental Staff, Research Laboratories, The General Electric Co., Ltd., North Wembley, Middlesex.

HAWORTH, Colin William, B.A., Research Student, Inorganic Chemistry Laboratory, University of Oxford.

HILL, Nigel Austin, Undergraduate, Department of Metallurgy, University of Birmingham.

HODGE, William Lang, B.Sc., A.R.I.C., Research Student, Inorganic Chemistry Laboratory, University of Oxford.

HUNT, Peter Ernle Guy, Trainee Metallurgist, Midland Laboratory Guild (1928), Ltd., King Alfred's Place, Broad Street, Birmingham 1.

JONES, Dudley De Gruchy, Undergraduate, Metallurgical Department, University College, Swansea.

LAWLEY, Alan, Undergraduate, Department of Metallurgy, University of Birmingham.

LOWTHER, William Henry, Student Metallurgist, South Durham Steel and Iron Co., Ltd., Middlesbrough, Yorks.

MORDIKE, Barry Leslie, Undergraduate, Department of Metallurgy, University of Birmingham.

O'DELL, Colin Sydney, Metallurgical Laboratory Assistant, The Fairey Aviation Co., Ltd., Hayes, Middlesex.

PIEARCEY, Barry James, Undergraduate, King's College, University of Durham, Newcastle-upon-Tyne.

POCOCK, Nicholas Jeremy Bernard, Undergraduate, St. John's College, Cambridge.

ROBERTS, Arthur Charles, Undergraduate, Department of Metallurgy, University of Cambridge.

ROBERTS, Ernest Graham, Undergraduate, King's College, University of Durham, Newcastle-upon-Tyne.

ROBINS, Clive, Metallurgist (trainee), Central Research Department, Dorman Long and Co., Ltd., Middlesbrough.

ROBINSON, James Frederick, Undergraduate, King's College, University of Durham, Newcastle-upon-Tyne.

ROSSER, John Dale, Works Metallurgist, Hunting Percival Aircraft, Ltd., The Airport, Luton, Beds.

SEAL, Arun Kumar, B.Sc., B.E.(Met.), Research Student, Department of Metallurgy, University of Sheffield.

STAFFORD, Jeffrey Samuel, Undergraduate, Department of Metallurgy, University of Manchester.

SUMNER, Gerald, B.Sc., Research Student, Department of Metallurgy, University of Manchester.

WOODWARD, Rodney, Undergraduate, King's College, University of Durham, Newcastle-upon-Tyne.

PERSONAL NOTES

DR. A. P. BAGCHI has left Manchester University and returned to India.

MR. K. T. BASSETT has left King's College, Newcastle-upon-Tyne, and has taken an appointment with The Fairey Aviation Co., Ltd., Hayes, Middlesex.

MR. R. G. BELLAMY has joined the Development Department of the National Smelting Co., Ltd., Avonmouth.

MR. G. CLOUGH has left Firth-Brown Tools, Ltd., and is now at the Thornton Research Centre of the Shell Petroleum Co., Ltd.

DR. R. A. DODD has resigned his appointment as Senior Lecturer in Metallurgy in the University of the Witwatersrand to take up a post in the Canadian Department of Mines, Ottawa.

LIEUT.-COLONEL W. G. DUMVILLE has been appointed Regional Manager, North East Region, British Insulated Callender's Cables, Ltd. He was previously Assistant Sales Manager.

MR. H. EVANS, Superintendent of the Development and Research Laboratory of The Mond Nickel Co., Ltd., has been elected President of the Birmingham Metallurgical Society.

MR. H. K. FARMERY has left Cambridge University and joined the staff of the Fulmer Research Institute, Stoke Poges, Bucks.

DR. H. J. FISHER has joined the staff of the Materials and Processes Section of the General Electric Company, Research Laboratory, Schenectady, N.Y. He was formerly with the Physical Metallurgy Division, Department of Mines and Technical Surveys, Ottawa.

MR. D. R. GODDARD has left A.E.R. (1938), Ltd., Enfield, to join the Research Staff of Imperial Chemical Industries, Ltd., Nobel Division, Stevenston, Ayrshire.

DR. A. E. JENKINS has been appointed Senior Lecturer in the School of Metallurgy, New South Wales University of Technology, Sydney, Australia. He was formerly a member of the C.S.I.R.O. Group attached to the Baillieu Laboratory, Melbourne University.

MR. W. E. J. LEWIS has retired from his position as Principal Surveyor for Metals, Lloyd's Register of Shipping.

DR. W. S. OWEN has left Liverpool University and is now working in the Department of Physical Metallurgy, Massachusetts Institute of Technology, Cambridge, Mass.

MR. E. C. W. PERRYMAN has been lent for two years by Aluminium Laboratories, Ltd., Kingston, Ont., to Atomic Energy of Canada, Ltd., Chalk River, Ont.

MR. D. J. PHILLIPS has left University College, Swansea, and taken a post with Rolls-Royce, Ltd., Derby.

MR. N. B. PILLING has been appointed Assistant to the Vice-President, International Nickel Co., Inc., New York. He was previously Director of the Company's Research Laboratory at Bayonne, N.J.

MR. R. PRASAD has returned to India from Cambridge and is now a lecturer at the College of Mining and Metallurgy, Benares Hindu University.

MR. C. E. PROSSER is retiring from his position as Chairman of the Metals Division of Imperial Chemical Industries, Ltd. He is to be succeeded by Dr. R. Beeching.

MR. STANLEY ROBSON has been nominated President of the Institution of Mining and Metallurgy for the year 1955–56.

MR. H. J. THACKER has left Reynolds Rolling Mills, Ltd., and taken a post with the Ministry of Supply.

M. P. VACHET has been appointed Assistant to the Chief Engineer of the Research and Physical Testing Department of the Pechiney Company.

PROFESSOR H. L. WALKER, of the University of Illinois, is at present at the Indian Institute of Science, Bangalore, under the technical programme of assistance from the U.S.A. to India.

DR. DEAN N. WILLIAMS has left the Kaiser Aluminum and Chemical Corporation and is now at Battelle Memorial Institute, Columbus, O.

MR. N. T. WILLIAMS has taken up an appointment with The Bristol Aeroplane Co., Ltd.

DR. G. K. WILLIAMSON has resigned his I.C.I. Fellowship in the Metallurgy Department at Birmingham University to take up a Senior Research Fellowship at the Atomic Energy Research Establishment, Harwell.

MR. A. L. WILSON has left Rolls-Royce, Ltd., and is now a metallurgist on the staff of the Northern Aluminium Co., Ltd., Banbury.

Death

The Editor regrets to announce the death of:

HERR SIEGFRIED JUNGHANS, Director of Gebrüder Junghans A.G., Schramberg, on 5 September 1954, aged 67.

NEWS OF LOCAL SECTIONS AND ASSOCIATED SOCIETIES

Birmingham Local Section

A Christmas lecture for the benefit of senior pupils at Birmingham Grammar Schools is being given again this year. It will take place at the Birmingham and Midland Institute at 2.30 p.m. on 13 December, when the lecturer will be Dr. W. O. Alexander of Imperial Chemical Industries, Ltd., Metals Division. His subject will be "Metallurgy and Its Kindred Sciences", and the lecture will be accompanied by practical demonstrations.

South Wales Local Section

At the first meeting of the session, held at University College, Swansea, on 12 October, Mr. D. E. Yeoman gave a lecture on:

Production and Manipulation of Titanium

He said that titanium promised to give rise to a massive metallurgical industry and, if this were the case, it would be only the third metal to be exploited so ambitiously since the Industrial Revolution. The history, occurrence, extraction, and consolidation of titanium were considered, so that the reasons for its relatively late appearance and for its present high cost became apparent.

The properties of high-purity and commercially pure titanium, together with the general characteristics of its alloys, were then outlined and discussed. The fabrication of both semi-finished and finished products was detailed, with particular emphasis on the precautions to be observed and on the general principles that had been evolved for overcoming difficulties. Finally, a brief account was given of the metal's industrial uses, both present and future.

JOINT ACTIVITIES

Joint Committee for National Certificates in Metallurgy

The following is a summary of the report on the progress of the scheme for the award of National Certificates in Metallurgy for the year 1953–54.

(1) The total numbers of approved Courses in operation during the session 1953–54 were:

Senior Courses for the Ordinary National Certificate, 37.

Contributory Centres, with Courses for the First Year or First and Second Years of the Senior Course, 6.

Advanced Courses for the Higher National Certificate, 20.

(2) Comparative figures of entries and successful candidates since the institution of the Scheme for National Certificates in Metallurgy in England and Wales are as follows:

Year	Technical Colleges	Entered	Number of Candidates		
			Total Awarded Certificates	With Distinction	With Prize Award
			I.—*Ordinary National Certificate*		
1946	4	28	23	4	7
1947	11	102	69	14	17
1948	15	123	74	12	16
1949	21	222	107	24	27
1950	20	281	142	23	26
1951	25	314	138	17	24
1952	28	334	186	22	31
1953	31	390	184	17	26
1954	37	522	not yet available		
		2316			
			II.—*Higher National Certificates*		
1946	...	...	...	...	...
1947	2	22	18	...	1
1948	8	38	22	1	2
1949	10	74	59	20	22
1950	11	62	42	8	10
1951	16	110	54	5	11
1952	16	132	120	16	22
1953	17	140	116	17	24
1954	18	173	144	22	31
		751	575		

The number of candidates taking an assessed examination in mathematics (1952–54) was 599.

(3) The Joint Committee has recorded its gratitude to the Assessors for their valuable assistance in the operation of the Scheme. Without this, its successful operation would not have been possible. (The Assessors have, in the year 1953–54, approved a total of 345 examination question papers and assessed the marks of 4234 examination scripts.)

(4) Notes for the guidance of Technical Colleges on the arrangement of courses for National Certificates in Metallurgy are being prepared.

Local Section Symposium

SOME TECHNIQUES OF CONSTITUTIONAL METALLURGY * B10

THE EXAMINATION OF SURFACE TOPOGRAPHY BY INTERFEROMETRIC METHODS

By W. D. BIGGS,† B.Sc., A.I.M.

Introduction

THE principles of optical interference are so well known that it is not proposed to discuss them here. Two-beam interferometers (e.g. the Zeiss–Linnik and Twyman–Green types) have been used for many years in optical and engineering workshops. The two-beam method produces an interference pattern in which the light and dark areas are of equal width (the intensity following a $\cos^2$ distribution), and although the method can be used at very high magnifications, fine surface detail may be obscured by the fringe width.

In two-beam interferometry the reflecting coefficient of the interfering surfaces is quite low; if this reflectivity can be increased by surface silvering, the $\cos^2$ intensity distribution is changed to a type of curve having a sharp peak intensity with a long flat minimum range, resulting from the use of a multiple system of interfering beams. This forms the basis of the Fabry–Perot Interferometer. It was left to Tolansky, however, to apply the method more widely, and to develop the techniques until a high degree of precision had been attained.

The optical principles have been thoroughly investigated,[1] and it is proposed here to deal only with the experimental techniques, particularly those of more recent development. Multiple-beam interferometry can be employed under surprisingly primitive conditions and with relatively little apparatus, the equipment consisting merely of a partially silvered glass reference surface in contact with the specimen; the fringes produced by a monochromatic light beam at normal incidence are then viewed with a standard metallurgical microscope.

Technique

The production of high-quality fringes (i.e. narrow fringes of high dispersion and contrast) requires that several important conditions be satisfied:

(a) *Surfaces to be Examined*

Highly polished or cleaved metal surfaces generally possess a high reflectivity, and for most purposes may be examined directly, although complications can arise from a doubling of the fringes due to the phase change occurring on reflection at non-normal incidence. For minimum fringe width, however, it is desirable that the surface reflectivity be at least 0·7. This necessitates silvering such metals as copper, iron, and zinc for the production of high-quality fringes. Silvering is, of course, essential on cleaved or polished mineral surfaces.

(b) *Reference Flats*

The use of expensive optically worked flats is not necessary, as the area under examination is quite small and good-quality plate glass has been demonstrated to be smooth and flat over such small areas.[1] For lenses of short working distance, a piece of selected photographic plate glass is satisfactory, or a thin glass bulb may be fractured and a suitable fragment silvered, though in this latter case the fringes will not be parallel.[2]

On a large irregular surface, e.g. a fracture, a flat makes local contact only, and the "microflats" suggested by Omar and Tolansky[3] have been found extremely useful. A small truncated cone (5 mm. base dia., 2 mm. tip dia.) is ground from plate glass of appropriate thickness and silvered in the normal manner. Despite the small area of contact, such a flat has sufficient rigidity to be mounted in a jig and pressure can be applied to the flat in order to shift the direction of contouring of the fringes.

For objectives of short working distance a simple oil-film technique has been described.[4] A carefully degreased and dust-free surface is coated with a thin film of Canada balsam or immersion oil and fringes are formed, the top surface of the oil being used as a reference surface. If the film is dried, it may be silvered, when a marked improvement in fringe quality results. The procedure suffers from several drawbacks; in particular the normal rounding of the oil film may be interpreted as a surface irregularity, and also there is no control over the direction in which the fringes cross a given contour. The technique is quite useful in cases where a glass flat might damage the specimen or where the surface structure of the glass might obscure fine detail.

(c) *Reflectivity of Reference Flats*

The fringe contrast $\frac{I_{\max.}}{I_{\min.}} = \left(\frac{1+R}{1-R}\right)^2$ holds for two surfaces of differing reflectivity, R_1, R_2, if R is replaced by $\sqrt{R_1R_2}$ Thus, if the reflectivity of the specimen surface be R_2, the reflectivity of the reference flat, R_1, should approach as closely as possible R_2. Holden[5] has demonstrated the change in fringe appearance with varying reflectivity of the reference

* Papers forming the basis of a Symposium organized by the Birmingham Local Section of the Institute and held in Birmingham on 26 February 1954.

† Department of Physical Metallurgy, University of Birmingham.

flat. Although the theoretical requirements are satisfied when $R_1 = R_2$, in practice it is often convenient to use a flat possessing a reflectivity which is a little higher than that of the surface and to obtain the necessary contrast photographically.

Since $R = 1 - (T + A)$, where T and A are the transmitted and the absorbed fractions of the beam, respectively, it is desirable that the absorption of silver on the reference flat should be as low as possible, and this requirement has necessitated a number of refinements in the original procedure. For most purposes a silver film is satisfactory, but silver films of low reflectivity possess a relatively high absorption (about 10%). They are also mechanically weak and tarnish in an ordinary laboratory atmosphere. Recently, the use of multilayer films of suitable dielectrics has been proposed,[6] and these are being extensively used in current investigations.

If the refractive index of the medium on the incident side of a dielectric is less than that of the dielectric itself, a phase change occurs, and hence, for a single film of optical thickness $\mu t = \lambda/4$ (t = metrical thickness), the reflectivity of the glass is increased if the refractive index of the film is greater than that of the glass. The light reflected at the dielectric/air interface undergoes a phase change π and is in phase with that reflected at the dielectric/glass interface which has traversed an additional path $2\mu t = \lambda/2$, equivalent also to a phase change of π. (The method is the converse of lens blooming, where the reflectivity of the surface is decreased by the use of a layer of low refractive index, viz. magnesium fluoride.)

By using a number of films of alternately high and low refractive index, each of optical thickness $\lambda/4$, reflectivities from 30 to 97% may be obtained with an absorption as low as 2%; the dielectrics found to be the most generally useful are zinc sulphide ($\mu = 2{\cdot}37$) and cryolite ($\mu = 1{\cdot}36$). The production of layers of the requisite thickness requires some experience, but Banning [7] has published data giving the interference colour of reflected white light for each appropriate $\lambda/4$ layer. The especial advantages of multilayer flats, apart from lower absorption, are their greater mechanical strength and tarnish-resistance and the wide range of reflectivities available, which permits fairly accurate matching of the flat with the sample.

Since the film thickness is $\lambda/4$ for green light, changing the wave-length of the light reduces the reflecting surface to effective transparency. Thus a normal micrograph and an interferogram of the same area may be recorded without disturbing the apparatus and, provided that sufficient care is taken with focusing, it is possible to superimpose an interferogram on a normal photomicrograph, even though neither image is of first-class quality.

(d) *Separation of Surfaces*

The production of very narrow fringes of high contrast is the most important modification to the Fabry–Perot fringes, and Tolansky has pointed out that the earlier workers overlooked the necessity for the interfering surfaces to be separated by a distance of the order of a few wave-lengths of light. This, surprisingly, is the most difficult condition to fulfil experimentally, although microflats or spherical reflecting surfaces assist materially on irregular surfaces. However, it is frequently necessary to examine a large area, and for this purpose a spring-loaded tilting jig is used, which permits a slight pressure to be applied, the direction of the thrust being varied so that the fringes are set in the desired direction across the feature to be examined. Considerable care must be exercised to avoid deformation of soft specimens or fracture or twinning of harder ones under the pressures sometimes needed to secure a sufficiently close approach of the surfaces.

(e) *Other Conditions*

The other essential conditions are more readily obtained, although for most practical purposes the desirable stringent parallelism of the incident beam may be somewhat relaxed, so that the normally collimated incident beam of a standard microscope is adequate; monochromatic light is obtained by using the green mercury line ($\lambda = 5461$).

(f) *Sensitivity*

Tolansky claims that ideally sharp fringes at a wide dispersion permit resolution of steps of 10 Å., but such sensitivity is rarely obtained in practice save under exceptional conditions. Our experience (mainly on unsilvered metallic surfaces) leads us to claim a sensitivity of about 50 Å., provided that a prior examination (say, under phase contrast) has given some indication of where to expect steps of this order. Angular sensitivity approaches the theoretical limit, and under good conditions a sensitivity of a few seconds of arc can be obtained.

(g) *Limitations of Interferometric Methods*

The greatest limitation is certainly that set by the lateral magnification, which should not exceed about $\times 400$; units smaller than $\frac{1}{300}$ mm. cannot be critically examined by this method.[8] Thus, multiple-beam interferometry may be regarded as complementary to two-beam interferometry, in which much higher lateral magnifications may be obtained though at the expense of some magnification in depth. The use of a reference flat and the matching of the reflectivities offer some difficulties, and work at present appears to be limited to room temperature or temperatures slightly above it. It is possible that multilayer flats may be employed for work at higher temperatures. However, the technique is extremely valuable where the expense of an electron microscope is not justified.

Applications

Interferometry has not as yet been widely applied to constitutional problems. The author's main interest is in the examination of plastically deformed and cleaved surfaces, so that most of the illustrations must perforce come from this field. The features which are commonly found in this type of work are steps varying in height from a few Ångstrom units to several microns, and angles generally of the order of a few degrees. These are clearly within the scope of interferometry and will be briefly discussed here.

(a) *Markings Due to Plastic Deformation*

Many examples have been published of the application of interferometry to slip markings on prepared surfaces.[9] The sensitivity of the method provides a ready means of detecting the earliest traces of plastic deformation. Surface tilting due to twinning is clearly shown, and a method employing Newton's rings has been used for studying the growth of twins in calcite.[10] In recent years, interferometry has been extensively used in investigations of creep behaviour (e.g. by Gifkins [11]), where the tilting of grains relative to each other and the slip traces in individual grains may be studied.

(b) *Hardness Indentations*

Nickols [12] has shown the characteristic fringe pattern of a typical hardness impression, and interferometric examinations have also been made of the anisotropy of diamond impressions

in single crystals[13] and of the deformation associated with indentations in polycrystalline materials.

(c) *The Study of Cleavage Surfaces*

Freshly cleaved surfaces of metal and mineral crystals reveal a wealth of detail which may be readily examined interferometrically, although the complexity of the patterns often makes interpretation rather difficult. Characteristic features include cleavage steps ranging from a few Ångstrom units to several microns in height,[14] twin traces with associated accommodation kinks, and low-angle mosaic boundaries.[15] Tolansky has studied mica cleavage and has shown that the cleavage pattern gives a much better idea of the impurity content of the mica than does a normal visual examination.

(d) *Surface Finish*

This is clearly a suitable application of interferometry, although there seems to be little connection with constitutional metallurgy, except possibly in studying those constituents which may stand in relief after polishing. The influence of surface finish on the fringe pattern, however, is plainly, though regrettably, obvious when studying slip on electropolished surfaces, where any surface ripple due to polishing leads to complex fringe pattern when superimposed on the fringe pattern due to slip.

(e) *Shear Transformations*

Williams, Cahn, and Barrett[16] have examined the $\alpha \rightleftharpoons \beta$ transformation in titanium, using an X-ray microbeam method, and have supplemented this by an interferometric examination of the surface tilts produced by the transformation from a body-centred cubic to a hexagonal lattice. They found that the surface tilts of the individually sheared areas lay between $3\frac{1}{4}°$ and $4\frac{3}{4}°$, which was inconsistent with the mechanism postulated by Burgers. The discrepancy may be associated with the accommodation mechanism; interferometric evidence of accommodation slip was observed.

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THE HOT-STAGE MICROSCOPE AND ITS USE WITH THE CINE-CAMERA

By S. G. GLOVER,* B.Sc.

Introduction

THE microscopic examination of metal surfaces at temperatures other than room temperature, although not a new technique, has only recently begun to receive the attention it deserves. The usefulness of the hot-stage microscope in the field of constitutional metallurgy is undoubtedly very great, for not only does it permit the examination of structures present at higher temperatures, but it may also yield information concerning the kinetics and mechanism of a phase transformation. It is in the study of the actual transformation processes that the cine-camera is valuable as a recording instrument.

Conditions Governing the Use of the Hot-Stage Microscope

Several papers describing various aspects of the technique of hot-stage microscopy have appeared in recent years,[1] and it is therefore unnecessary to give a general account of the method in this paper, and attention will be confined to the more important principles involved.

The basic criteria for the application of this method of investigation of the constitution of alloys are: first, that the phases may be differentiated and, secondly, that observations made of conditions at the surface of the material are valid for the whole volume. Phases may be distinguished in several ways. They may show inherent differences in colour in reflected light, or some form of thermal etching may be employed to differentiate the phases. If one phase is anisotropic, it can be revealed by illumination with polarized light; if a transformation proceeds by a shear mechanism, relief effects are produced on an initially plane surface.

Where the observation of fine detail is important, difficulty is encountered in the use of an objective of sufficiently high resolving power because it is usually necessary to protect the specimen surface from oxidation at high temperature by heating in an inert atmosphere or *in vacuo*, using a window between the objective and the specimen. Furthermore, the specimen–objective distance must be sufficient to obviate excessive heating of the objective. Each of these factors makes it necessary to use an objective with a long working distance, and this is normally associated with a low resolving power. The construction of

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objectives having long working distances combined with high numerical aperture and resolving power has been described in detail ;[2] in general, a reflecting objective is used.

The Observation of Shear-Type Transformations

Shear-type transformations, the best-known example of which is the martensitic transformation, are characterized by the maintenance of lattice registry between the parent and the new phase during the formation of a crystal of the latter. The new phase is formed by the ordered movement of atoms in such a manner as to produce a distortion, and, in consequence, relief effects at the surface, the process being somewhat analogous to that of mechanical twinning.

Transformations of this kind are particularly amenable to study by hot-stage microscopy, since they may be followed by observation of the changes in surface topography. Moreover, they normally occur at relatively low temperatures and much important information can be obtained at a low magnification. Both these factors contribute to simplicity of technique. It is sometimes necessary, however, to work over a temperature range extending below room temperature and a suitable " high–low " stage for this purpose has been described.[3]

A simple apparatus which has been used in investigations of martensitic and bainitic transformations is shown in Fig. 1. It consists of brass plate having a recess in which the specimen is held by beryllium copper clips. A silicone rubber ring, cut from sheet, acts as a seal between the brass plate and the cover glass. The plate is drilled to allow evacuation of the specimen chamber and the insertion of a thermocouple, the tip of which

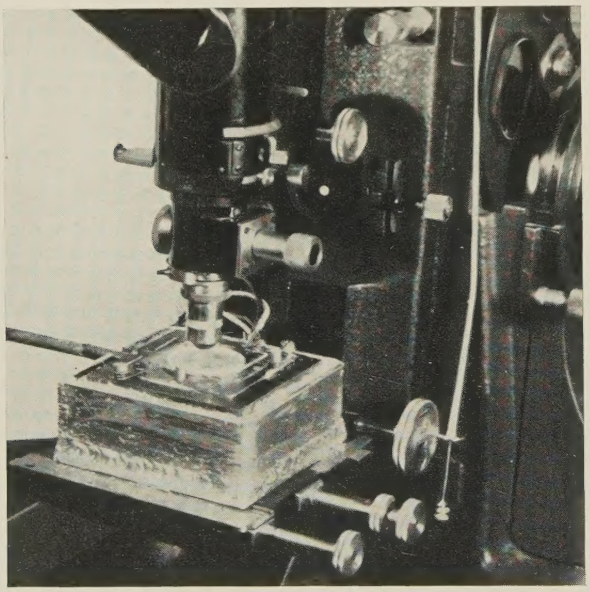

FIG. 1.—Hot Stage Mounted on a Leitz Projection Microscope.

is located 0·010 in. below the surface of the plate and beneath the mid-part of the specimen. The furnace in which the brass plate is seated consists of a block of copper carrying a Nichrome resistance winding. Using a 16-mm. objective (working distance 4 mm.), the upper temperature limit of the stage is governed by the maximum working temperature of the silicone grease (approx. 200° C.). The specimen chamber is either continuously evacuated by a single-stage rotary pump producing a vacuum of the order of 10^{-2} mm. mercury, or the pressure is reduced to this value and the chamber sealed off.

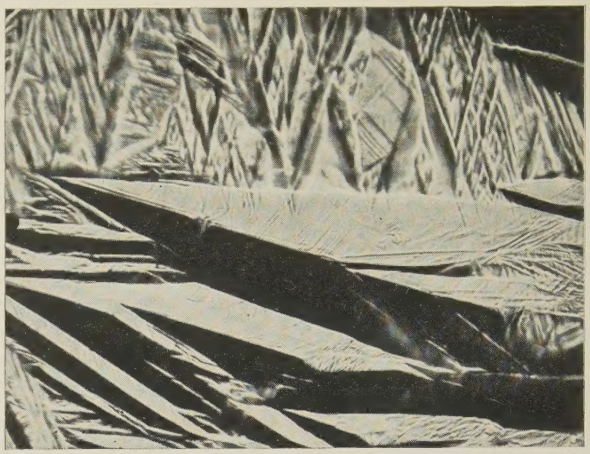

FIG. 2.—Surface Tilting Due to Martensite Formation Viewed under Slightly Oblique Illumination. 16-mm. objective. × 200.

The stage may be mounted as shown or in the inverted position.

Fig. 2 is included as an example of the appearance of the surface of the specimen after a shear transformation has taken place. In this instance, oblique illumination (obtained by displacing the illuminating beam from the normal optical axis) was employed to reveal the tilting of the surface.

The Use of the Cine-Camera

The film recording of phase transformations made visible by the hot-stage microscope is of value because it permits a more quantitative approach than does ordinary observation under the microscope. Moreover, the film may be projected at a speed which differs from that of photographing, so that the changes taking place become more evident. This may involve, perhaps surprisingly, an apparent speeding-up of the process.

A cine-film of the martensitic transformation in steel was made in Germany before the last war, and recently the actual formation of individual martensitic crystals has been photographed by this method.[4, 5] It should be added that these observations were made on alloys which transform in a rather unusual manner in that at least part of the growth process of the martensitic crystals occurs slowly; the possibility of recording the actual formation of a martensitic crystal in the normal manner (within a time of the order of 10^{-7} sec.), as for instance in steels, seems remote by any photographic technique and certainly impossible by means of the cine-camera.

The technique adopted at Birmingham, which has the advantage that the apparatus consists of standard components, is to mount a Paillard–Bolex 16-mm. camera (with lens removed) on the projection tube of a Leitz projection microscope. The projection eye-piece and the distance of the film from the projection eye-piece are chosen to give the required secondary magnification. In order to focus the image in the plane of the film, the camera-gate is removed and a prism having a ground-glass screen is inserted in place of the film. Ilford F.P.3. film has been found to be satisfactory.

A film has been made under the auspices of B.I.S.R.A.

(based on the work [6] of Dr. T. Ko and Dr. S. A. Cottrell, both formerly of the Department of Metallurgy at Birmingham) that is designed to show the contrast in mode of formation of martensite, which occurs by a rapid shear-type transformation, and that of bainite, which, though involving some kind of shearing mechanism, forms slowly.

The film illustrates admirably the possibilities of the technique and also demonstrates the care needed in the interpretation of observations made by this method, for although the almost simultaneous formation of a group of martensite plates is by no means unknown, some doubt exists as to whether this "bursting" takes place at regions other than the surface in this particular steel.

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EXAMINATION OF METALLIC SURFACES BY ELECTRON-DIFFRACTION METHODS

By E. C. WILLIAMS,* M.Sc., A.Inst.P.

Introduction

ELECTRON-DIFFRACTION methods have been in use for over twenty years in studies of the structure of matter. It might be argued that during this period their contribution to knowledge has not been as great as that of X-ray methods. In making comparisons, however, the special nature of electron-diffraction investigations should be borne in mind, and it is the purpose of this short paper to emphasize their particular scope and limitations when applied to metallic surfaces. By way of illustration some original results relating to a polished silver surface are discussed.

General Principles

The theory and practice of electron diffraction has been expounded in two standard works,[1, 2] and reference need only be made to certain main principles.

The small de Broglie wave-length of electrons accelerated in fields of the order of 50 kV. ($\sim$0·05 Å.), commonly used in practice, means that sharp or highly resolved patterns are produced by crystals of 50 Å. and less in linear dimensions. With X-rays ($\lambda \sim 2$ Å.) the lower limit of crystallite size for sharp definition of diffracted beams is about 1000 Å. Electrons propagated through matter have a high absorption coefficient, so that the examination of structure is confined to extreme surface layers of solids, very thin films, or fine powders. Because of the high resolving power it is also possible to estimate bond-lengths in the molecular structure of gases and vapours by analysis of the intensity of diffuse scattering.

The scattering of fast electrons by the nucleus of an atom is approximately 10^7 times as efficient as the scattering of X-rays by its electron shells, and the intensity of diffraction by a crystal is sufficient to make the effects visible on a fluorescent screen; consequently, exposure times for photographic recording are only of the order of seconds. This high scattering power provides great sensitivity, and so only minute quantities of diffracting material are required. Under favourable conditions, the techniques can be used for quantitative micro-analysis by the well-known procedure of identification from diffraction patterns. On the other hand, diffraction by minor constituents may sometimes mask that due to a specimen as a whole, and care is accordingly necessary in the interpretation of results. In fact, many experimental and interpretational difficulties arise from accidental or unavoidable contamination.

The interpretation of diffraction patterns bears some similarity to that of X-ray patterns, especially in the case of polycrystalline aggregates when the radii of diffraction rings are commensurate with the spacings of corresponding reflecting planes. With single crystals, or specimens containing only a few grains, several secondary effects which have no counterparts in X-ray diffraction are noticeable. They include, for example, the famous Kikuchi lines formed by the diffraction of electrons which have lost part of their primary energy through inelastic collisions within the same crystal, and cross-grating patterns due to two-dimensional diffraction from particular atomic planes, modified to a greater or less extent according to the relaxation of the Laue condition associated with the third dimension. This relaxation varies inversely, so to speak, as the effective length of the diffracting part of the crystal in that direction. In practice, it will be limited either by the thinness of a lamellar crystal through which electrons are transmitted or by the small depth of penetration below a surface grazed by electrons. The cross-grating pattern is directly related to the reciprocal lattice and is of value in the analysis of unknown crystal structures.

Application to Metallic Surfaces

Metallic surfaces are investigated by the grazing-incidence or "reflection" technique, with the incident beam striking the surface at an angle usually much less than 1°, as required by the smallness of the Bragg angles. Because of the low penetrating power of the electrons, only the tips of the asperities on a surface will contribute to the diffraction, and the intensity and other characteristics of the pattern will depend on their number and contours. Satisfactory patterns are therefore obtained only when the surface is plane and fairly smooth in the macroscopic sense. This condition restricts application of the technique, and from experience it must be said that its potentialities are least, and the results sometimes disappointing, when it is used in investigations of an *ad hoc* nature, or in

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occasional identification problems involving surfaces which cannot, for one reason or another, be specially prepared. They are greatest under specially chosen experimental conditions when the topography of the surface can be controlled to some extent.

A disadvantage of the technique is that interplanar spacings cannot normally be measured with an accuracy greater than 1%. In X-ray diffraction the facility with which lattice parameters may be determined to an accuracy of at least 0·002% is of great value; it has contributed, for example, to an understanding of solid-solution alloys, and makes possible the accurate plotting of phase boundaries in alloy systems. With electron diffraction an improvement is possible under special conditions and some results of more accurate measurements at metallic surfaces have indicated that over the very restricted volume of crystals below the free surface to which the measurements necessarily refer, large lattice strains exist. These strains may be associated with natural imperfections of the structure or with occluded gases.

The extension of most physical techniques for the investigation of structures in order to allow observations to be made on specimens maintained at elevated temperature usually involves some sacrifice of flexibility, precision, or ease of operation. With electron diffraction the practical difficulties are less than with optical microscopy or X-ray diffraction, and a simple type of hot stage makes possible the investigation of heated surfaces in the vacuum of the electron-diffraction camera. Such a device is useful in studying high-temperature oxidation, for instance, oxygen being admitted at controlled pressure into the working chamber of the apparatus.

Typical applications include studies of the structure and chemical identity of solid reaction products forming on a surface, the structure of electrodeposits and other coatings, the behaviour of boundary-lubrication films, and the structure of the metal itself at, and near to, its free surface. The term " structure " is used here to denote crystal structure as such and conditions related to it, such as preferred orientation and crystallite size. To a limited extent information regarding the microtopography of a surface may be derived from certain features of diffraction patterns.

A considerable volume of information has accumulated with regard to such applications, and many valuable conclusions have been drawn regarding the nature of surface forces and the mechanism of surface reactions. Much of the experimental work, however, appears to have been only exploratory in character. It is becoming increasingly evident that the particular structural state at a surface influences its physical and chemical behaviour and, so far, only a few investigations of surface phenomena by electron diffraction, or indeed by other techniques, have been aimed at the elucidation of this factor. It must also be admitted that many details concerning the variations in structure of a metallic surface according to the method by which it has been prepared are unknown. The sensitivity and power of the electron-diffraction method in providing information on the structure in regions extending over a few tens of interatomic distances should permit closer investigation of such problems. In particular, the preparation of a surface should be designed so that maximum use can be made of this sensitivity.

Examination of a Polished Silver Surface

The progress of what appeared to be, in concept, a comparatively straightforward experiment is a striking illustration of how factors previously unknown or not anticipated produce unexpected electron-diffraction results. A specimen of silver, nominally 99·8% pure, was polished with diamond dust and heated in the vacuum of the electron-diffraction camera (residual pressure, 0·001 mm. mercury), the object being to determine the temperature and pressure of pure oxygen at which silver oxide is formed, and thereafter the stability of this oxide as a film in contact with its parent surface at different temperatures.

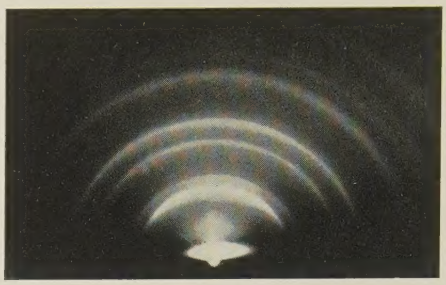

FIG. 1.—Diffraction Pattern of Silver Surface Polished with Diamond Dust.

Before oxygen was ever admitted to the specimen it was observed that the original diffraction pattern representing randomly oriented silver crystallites (Fig. 1) changed as the temperature was increased. The new pattern (Fig. 2) was first clearly observed at about 200° C., and it indicated a face-centred cubic structure with the lattice parameter of copper,

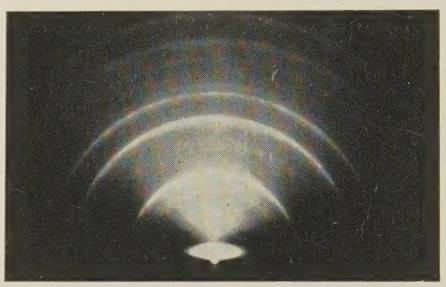

FIG. 2.—Diffraction Pattern of Copper Layer appearing on the Surface of Polished Silver on Heating *in Vacuo* to 500° C.

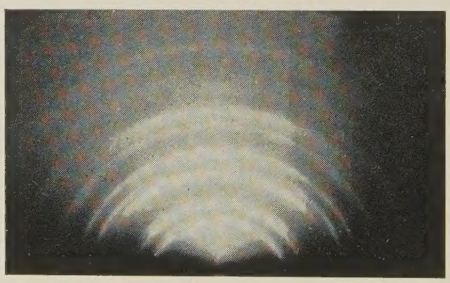

FIG. 3.—Diffraction Pattern of Oriented Cupric Oxide after Oxidation of the Copper-Bearing Silver Surface at 500° C. in Pure Oxygen at a Pressure of 5 mm. Hg.

the (200) reflection being very weak and the (111) strong; some diffraction by the underlying silver is also visible in this pattern.

After oxidation for 4 min. in oxygen at a pressure of 5 mm. mercury, with the specimen at 400° C., cupric oxide in a

highly oriented form was observed (Fig. 3). A spectrographic test of the silver indicated a copper content of the order of 0·02%.

As previously emphasized, results of this nature must be interpreted with caution. Contamination of the surface with copper originating in the form of vapour from certain parts of the hot stage, although considered to be unlikely at the temperatures involved, was suspected. In a similar experiment with an iron surface, carried out under identical conditions, copper was not detected, and it thus appeared that in the case of the silver specimen the source of copper was the small quantity occurring in the metal itself as an impurity.

A tentative explanation of the above observations is that copper atoms diffuse to the free surface, where they spread out to form a continuous layer, and, apparently, crystallize so that (111) planes of the copper lattice lie parallel to the surface. The apparent rapidity of the diffusion at comparatively low temperature is surprising, but not incompatible with what is known of surface-diffusion effects in general. This particular phenomenon was first discovered by Langmuir in thoriated tungsten, but it has not often been observed since.

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ELECTRON-OPTICAL METHODS IN CONSTITUTIONAL METALLURGY

By J. W. MENTER,* M.A., Ph.D., A.Inst.P.

Introduction

Since the first electron microscope was constructed in the early thirties, the main effort in instrument development has been directed towards improving the performance of the conventional transmission type of microscope, which is now capable of a resolution of the order of 10 Å. While transmission instruments of high resolution find many fields of application, particularly in the biological sciences, where extreme resolution is essential, there are some other fields, for example, in metallurgy, where a poorer resolution is acceptable, especially if, in compensation, the possible scope of experiments is increased. Thus, in recent years, taking advantage of the advances in knowledge and technique accruing from the intensive effort put into the development of the transmission microscope, a number of workers have re-examined some of the earlier ideas for instruments in which it is possible to examine solid surfaces directly by electron-optical methods. Before embarking upon a detailed examination of the possibilities of these methods, it is proposed to discuss briefly the uses and limitations of the transmission microscope in problems of constitutional metallurgy.

It is, perhaps, worth reminding ourselves at the outset that a limitation common to all methods of surface study in constitutional metallurgy arises from the fact that events occurring on the surface may not be representative of changes within the bulk of a material. This limitation becomes particularly severe when we wish to make a continuous study of a transformation taking place mainly within the bulk of a material by observations upon its surface. For the static specimen, i.e. one which is in an equilibrium state, the difficulty may be avoided by sectioning and observing the structure of the surface of the section after polishing and etching. This is the method which is commonly employed with the transmission electron microscope. At the voltages normally employed, a specimen for examination in this instrument must be no thicker than about 1000 Å. This means that if we wish to study the micro-geometry of an etched section a thin plastic replica of the surface must be made. We interpret the thickness variations of this replica in terms of the micro-geometry of the original surface as indicated in Fig. 1. Many variations of this technique have now been devised, but the well-tried

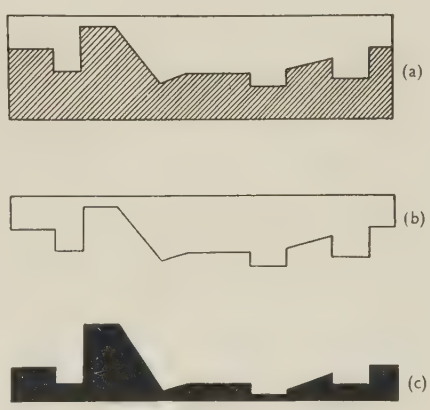

Fig. 1.—Schematic Representation of Formvar Replica Technique.
(*a*) Formvar Film Cast on Solid Surface.
(*b*) ,, ,, Removed from Surface.
(*c*) Contrast System of Replica (ordinates indicate blackening of photographic plate).

Formvar replica has been found adequate for most purposes. A typical micrograph of a pearlitic steel made by this method is shown in Fig. 2. (If the solid specimen itself happens to be exceedingly thin, it is possible to examine its surface structure directly in the transmission microscope after oblique metal shadow-casting to enhance the contrast of the surface features. A particularly elegant example af this method is the study by Dawson and Vand [1] of surface spirals associated with screw dislocations in the growth of crystals of long-chain hydro-

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carbon compounds. This is only possible because of the plate-like habit of these crystals which permits the growth of very thin specimens.) In the interpretation of replicas we are guided by very much the same sort of principles as apply in optical metallography, i.e. the nature of various phases may be determined according to their etching properties, shape, size, and distribution.

The transmission microscope may be used with advantage

FIG. 2.—Formvar Replica of Pearlite. × 10,000. (Reduced by one-half in reproduction.)

in another way in studying the constitution of a specimen. If one of the phases occurs in the form of small precipitated particles, it is often possible, by using a suitable electrolytic technique, to extract these particles and, after dispersing them upon a suitable supporting film, to examine them by transmission in the electron-microscope. Fig. 3 shows a micrograph of carbide particles extracted from a steel.

In the three-stage microscope, this type of study may usefully be combined with electron diffraction from a selected area of the specimen of the order of a few microns in diameter. Thus, if the extracted particles are thin enough, additional valuable information may be gained about their identity and crystal structure. This method has obvious advantages over X-ray methods of identification, particularly when the crystals are very small and few in number. An interesting illustration of this method is the identification by its crystal structure of a chromium carbide phase ($Cr_{23}C_6$) in a 25 : 20 Cr–Ni steel by Brown and Clark.[2]

While these transmission methods have certainly proved their worth, it is clear that they suffer from the serious inconvenience that the intact specimen itself is not examined in the microscope. Thus the type of information that may be obtained from the replica, and the experiments that may be performed with the specimen are severely restricted. In particular, the replica method is essentially static in the sense that experiments must be conducted outside the microscope and the replica of the surface made at a particular point in the experiment thought to be of interest. Moreover, this must usually be done at room temperature, and this means, for example, that if high-temperature transformations in alloys are being studied, an attempt must be made to retain the high-temperature structure by rapid quenching.

In order to compare the merits of conventional transmission microscopy with the other methods discussed below, some mention should be made of the possible resolution achievable in transmission. Formvar replicas seldom show a resolution better than 200 Å., and they are therefore not capable of taking full advantage of the instrumental resolution of modern microscopes. Recent work has shown, however, that this limitation arises from the self-structure existing within the body of the Formvar film rather than from a failure of the film accurately to contour the surface. With the carbon-replica method recently developed by Bradley,[3] it appears possible to obtain replicas having a self-structure no greater than the instrumental resolution, i.e. about 20 Å. In metallurgical work there has been some argument as to whether there is much purpose in striving for resolutions better than those given by the Formvar replica. It has been argued that there is little of importance in the structure of a metal with dimensions less than this order of magnitude. Recently however, Nutting,[4] using the carbon replica has shown the existence of exceedingly small grains, 1–200 Å. in dia., in a boron–molybdenum steel, so it would seem that the previous attitude of metallurgists to high resolution has grown up more from resignation to what they were given than from any considered argument. Nevertheless, there is still much to be said for an instrument in which the surface of the specimen itself is studied, even though the resolution may not approach that achievable in the transmission microscope.

The direct methods of electron microscopy may be broadly classified into those in which the surface is made self-luminous in the electron-optical sense (emission microscopy) and those in which the image of the surface is formed with secondary electrons obtained by bombarding the surface with a primary beam of electrons or ions.

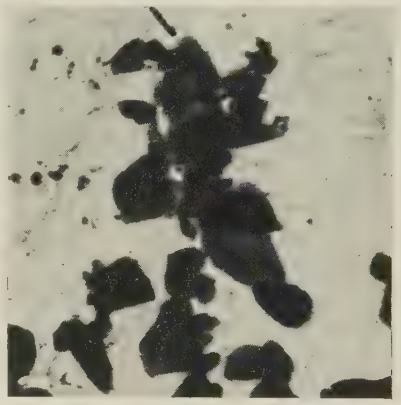

FIG. 3.—Transmission Micrograph of Cementite Particles Extracted from Steel. × 10,000.

Emission Microscopy

Electrons may be obtained from a surface either by so-called cold emission or by thermionic emission. The former method is used in the cold-field emission microscope developed by Müller,[5] Benjamin and Jenkins,[6] and others. There appears at the moment to be little prospect of using this technique in constitutional metallurgy, but since it gives perhaps the most highly magnified image of a metallic surface so far obtained, brief mention of it will be made. Electrons are obtained from the surface of a metallic point of exceedingly small radius by applying a potential of the order of a few thousand volts between the point and an Aquadag anode painted on the inner wall of an evacuated glass envelope enclosing the point (Fig. 4).

On account of the very small radius of the point, the field in its neighbourhood may reach a value of 50,000,000 V./cm.

Under the influence of this strong field, the shape of the potential barrier at the surface is changed so that electrons are able to leave the surface by the tunnel effect. The electrons strike a fluorescent screen on the end of the tube and there form an image of the surface, the contrast in which is determined

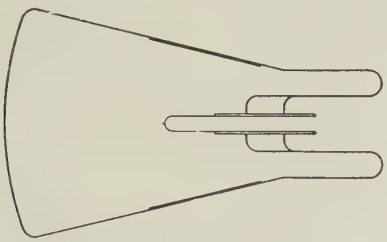

FIG. 4.—Schematic Section of Field-Emission Microscope. (*After Müller.*[5])

by variations in the electron emission from different parts of the surface. The emission current is governed by the Fowler–Nordheim relation and is a function of the electric field (E) and the work-function (ϕ) at the surface, viz.

$$I \propto \frac{E^2}{\phi} \exp\left(\frac{-\phi^{3/2}}{E}\right)$$

Thus, variations in the emission current arise mainly from variations in ϕ on different crystallographic planes and local changes in E arising from the micro-geometry of the surface. Since the field is spherically symmetrical, the magnification of the system is given by the ratio of the distance between point and screen and the radius of curvature of the point. A typical value of the possible magnification is 10^6, with a resolution of the order of 10–20 Å. Müller [7] has recently constructed an apparatus to which hydrogen is admitted at low pressure and with a reverse field uses protons to form the image, the protons arising from the dissociation of hydrogen molecules adsorbed upon the surface. With this system, even higher resolutions are possible and Müller claims to have resolved the edges of individual atomic planes on a tungsten point. It would seem that this technique is not very well suited to general metallurgical investigations, since the type of information imparted by the image is rather limited and, moreover, its use is confined to specimens which can be prepared in the form of very small points and to metals which can be cleaned without evaporation by raising them to a very high temperature *in vacuo*. An extensive review of the method has been made recently by Müller.[8]

The microscope using thermionic emission is much more promising in its general applicability. The development of the first microscope to employ this principle occurred almost simultaneously with the development of the first transmission electron microscope and was described by Brüche and Johannson.[9] A number of workers have since improved the original design, and some interesting metallurgical investigations have been carried out. Electrons are obtained from the surface under investigation by heating it to a high temperature. The surface forms the cathode of a so-called immersion lens, usually electrostatic, the electrons being accelerated off the surface by the field between the surface and the next electrode of the lens, which forms a magnified image of the surface. This image is then magnified further by a projector lens, as in the conventional electron microscope (Fig. 5).

To obtain emission from the cathode surface at reasonable temperatures, it is generally necessary to deposit an activator such as cæsium or strontium upon the surface to lower the work-function. Thus, contrast in the image arises from differences in electron emission due to differential adsorption of these active materials on different crystallographic planes exposed at the cathode surface. It is then possible to distinguish the grain structure, and hence the phase structure, of the surface. The instrument has been extensively used for the study of the emission properties of different cathode materials. Since, with activators, thermionic emission can be obtained over a considerable temperature range below the melting point of many metals, the method has also been used to study phase transformations directly. Thus Brüche and Knecht [10] and Burgers and van Amstel [11] have studied the $\alpha \rightarrow \gamma$ transformation in iron, and the latter authors have also studied the martensitic type of transformation associated with the transition from the cubic β modification to the α hexagonal modification of zirconium at about 865° C. More recently, Rathenau [12] and his collaborators have studied the grain growth associated with phase changes in iron–silicon alloys. In Fig. 6 is shown a typical sequence of changes observed in the austenite–pearlite transformation by Rathenau and Baas.[13]

The best resolution achieved to date with this technique is 400 Å. by Mecklenburg,[14] but this does not approach the theoretical limit of 60 Å. predicted by Recknagel.[15] The main limitations of resolution arise from the chromatic spread of the velocity of emission of the thermionic electrons and the electrical breakdown of the vacuum between the electrodes of the immersion lens.

The thermionic-emission electron microscope is thus a valuable tool in constitutional metallurgy for the direct study

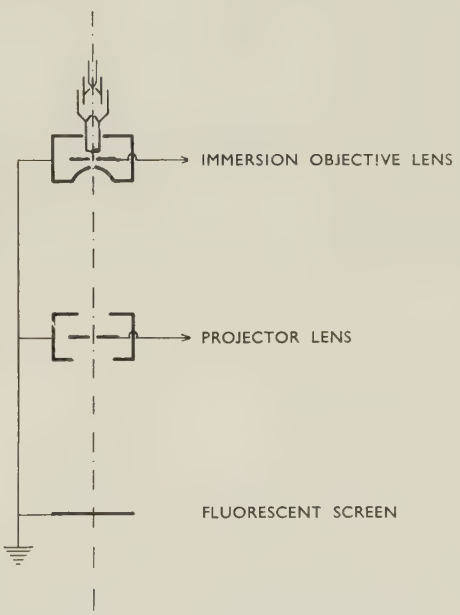

FIG. 5.—Schematic Section of Thermionic-Emission Electron Microscope. (*After Gauzit and Septier.*[37])

of grain growth and phase changes at elevated tempertures, at a reasonable resolution. In this respect it is superior to optical methods using a hot stage, which give only a limited magnification and resolution on account of the long working distance it is necessary to use between objective and specimen in order to avoid damage to the lens. The range of temperatures in which studies may be made with the emission microscope is limited, however, to those in which it is possible to obtain reasonable emission currents from the surface either with or without activators.

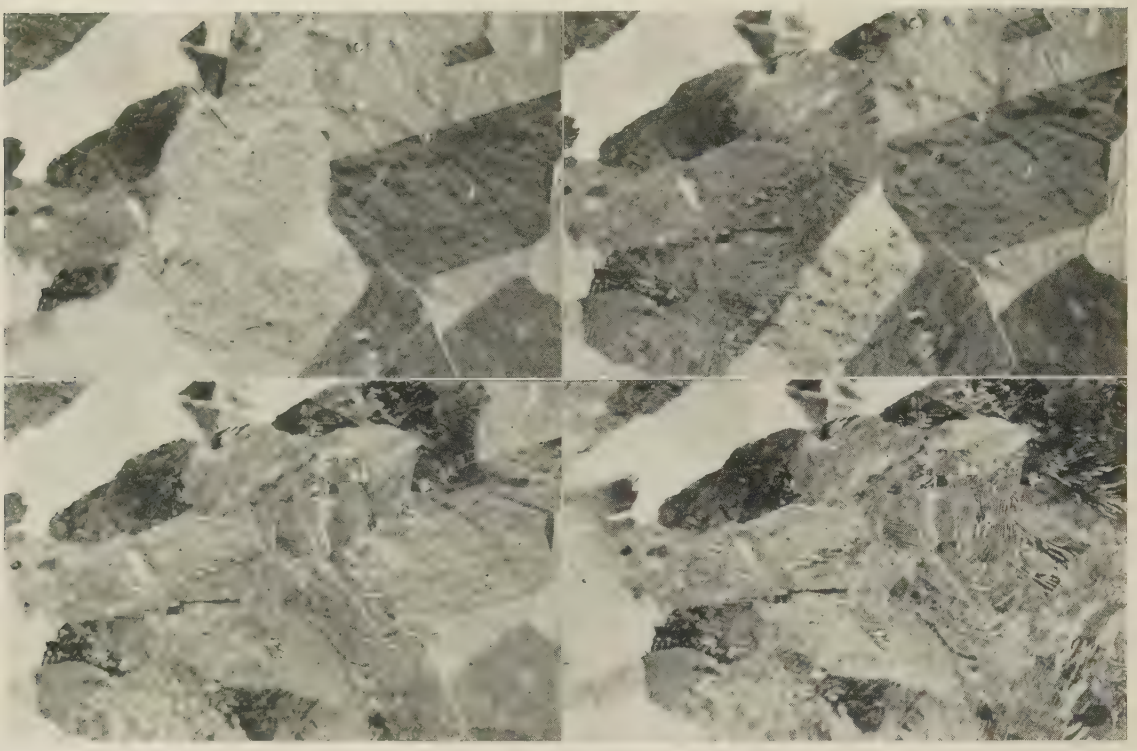

FIG. 6.—Sequence of Micrographs showing Growth of Pearlite Colonies across Austenite Grains Taken in Thermionic-Emission Electron Microscope. (*Rathenau and Baas.*[13]) × 750. (Reduced by one-third in reproduction.)

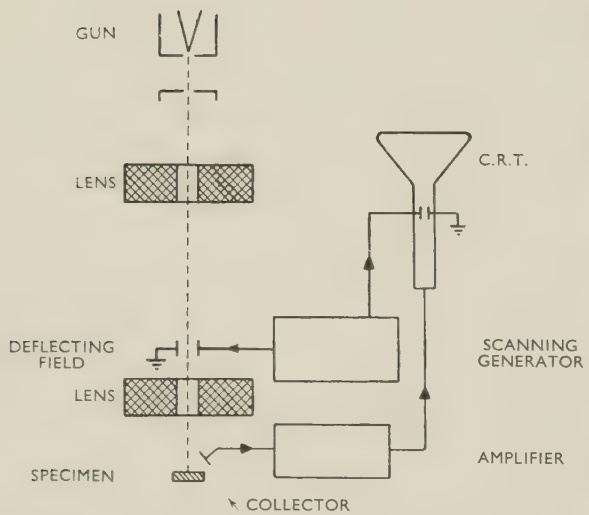

FIG. 7.—Schematic Diagram of Scanning Electron Microscope. (*McMullan.*[18])

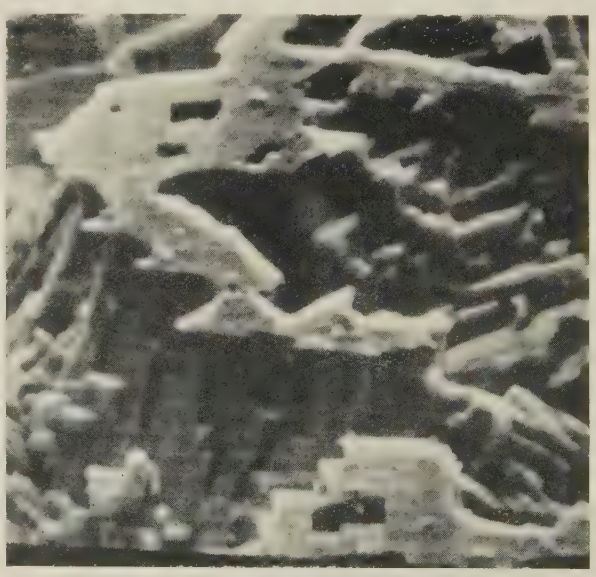

FIG. 8.—Micrograph of Etched Aluminium Surface Taken in Scanning Electron Microscope. (*McMullan.*[18]) × 4000.

Secondary-Emission Microscopes

The necessity of heating the specimen may be avoided by using a method in which the electrons are obtained from the surface as a secondary beam by bombarding the surface with either electrons or ions. A number of instruments of this type have been devised, and each will be briefly discussed.

Scanning Microscope

Scanning electron microscopes have been constructed by von Ardenne,[16] Zworykin, Hillier, and Snyder,[17] and McMullan.[18] The most successful has been that of McMullan, recently completed in the Engineering Dept., Cambridge. In this instrument, magnetic lenses are used to form a highly demagnified image of an electron source. This very small electron spot, of the order of 500 Å. in dia., is then scanned across the specimen surface in a raster, by suitable deflecting fields, as in a television system, and the secondary electrons emitted under the influence of the primary bombarding beam are collected into an electron multiplier. After amplification, the signal is used to modulate the beam of a cathode-ray tube which traverses the fluorescent screen of the tube in synchronism with the scanning spot in the microscope (Fig. 7).

The number of secondary electrons emitted at a given point on the surface is determined both by the micro-geometry of the surface and the atomic number of the material, and contrast in the image built up on the screen of the cathode-ray tube may arise from either of these effects. The surface may be viewed either with the scanning beam at normal incidence, when the contrast effect of atomic number is predominant, or with the beam striking the surface obliquely, when, if the surface is etched, contrast arises mainly from shadows cast by surface asperities. Fig. 8 shows a typical micrograph of an etched aluminium surface obtained by McMullan, the angle of incidence of the electron beam on the surface being 25°.

The resolution claimed by McMullan for this instrument is about 500 Å. and is limited in his case by astigmatism in the lenses and stray magnetic fields. When these have been removed, he believes a resolution of 100 Å. may be obtained. Limitations are imposed upon the resolution by the smallness of the electron spot it is possible to obtain and by spreading of the image points on account of lateral scattering of the beam penetrating beneath the surface of the specimen. This instrument is essentially designed for examining surfaces directly, and while the same principle may be used to obtain transmission images, it is much inferior for this purpose to the conventional transmission microscope on account of its poor inherent resolution. It is possible, in principle, to conduct experiments upon the specimen while it is under observation, although this has not yet been done. The rate of contamination of the surface in this instrument is very low, and this may prove an advantage over other methods (see below). The auxiliary electronic equipment of the microscope is somewhat formidable, and we must await the results of metallurgical investigations with the instrument before judging whether they justify this complexity when compared with the simpler methods to be described.

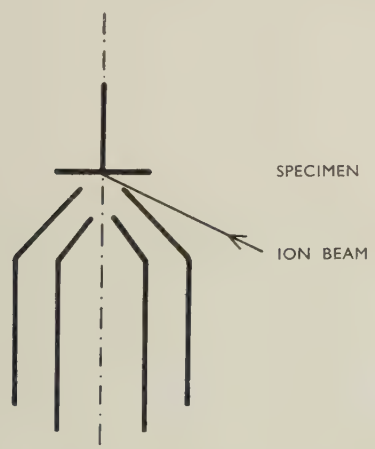

Fig. 9.—Schematic Section of Immersion Objective in the Microscope of Möllenstedt and Düker.

Fig. 10.—Micrograph of Etched Pearlite taken in the Secondary Emission Microscope of Möllenstedt and Düker.[19] × 2500. (Reduced by one-quarter in reproduction.)

Secondary-Emission Microscope with Positive-Ion Bombardment

Möllenstedt and Düker [19] have recently devised an electron microscope for the direct study of surfaces, in which the image is formed by secondary electrons emitted from the surface as a result of bombarding with a 40-kV. beam of positive ions. The specimen is arranged with its surface normal to the axis of the instrument and forms the cathode of an electrostatic immersion lens. The ion beam is directed on to the surface at a glancing angle of 30°, and the electrons accelerated off the surface by the central electrode of the immersion lens form an image which is further magnified by a projector lens (Fig. 9).

The energy spread (ε) of the electrons emitted under these conditions is remarkably low, of the order of 2 eV. only. The resolution is given by an expression of the form:

$$\delta = \varepsilon/E$$

so that with a field (E) at the surface of 150 kV./cm., a resolution of 1000 Å. is readily achieved. Fig. 10 shows an etched pearlitic steel specimen imaged in this microscope with a resolution of 900 Å.

Contrast again arises mainly from shadows, since electrons

are emitted only from those parts of the surface actually illuminated by the ion beam. Möllenstedt states that, in the initial stages of observation, contrast may also be observed on account of the different secondary-emission properties of materials of differing atomic numbers. This effect is rapidly obscured, however, as a result of the formation of a uniform film of chemically homogeneous contamination on the surface. The surface may also suffer damage under prolonged bombardment by the ion beam. Again, provided that there are no deleterious effects upon the functioning of the immersion objective, it should be possible in principle to carry out dynamic experiments upon the surface while keeping it under continuous observation. The surface is viewed normally so that the image imparts information in many ways complementary to that obtained with the glancing-incidence reflection microscope described below.

Reflection Electron Microscopes

The direct imaging of a surface by using the scattered electrons that arise when an electron beam falls upon the surface was first experimentally achieved by Ruska.[20] The method used was later improved by Ruska and Müller,[21] who used a standard electron-optical system of objective and projector lenses. The specimen was inclined at 45° to the axis of this system, and the primary electron beam directed on to the surface at an angle of 45° (Fig. 11).

The electrons forming the image suffered a deviation of 90° and thus lost a considerable amount of energy, resulting in a high chromatic aberration in the image. Furthermore, the intensity of the electron beam scattered through this large angle is small. For these two reasons, images of poor quality and low magnification were obtained. Von Borries[22] showed how to overcome these difficulties by using a comparatively small angle of deviation of the beam. He inclined the illuminating system of a conventional transmission electron microscope at an angle of 8° to the vertical axis. The specimen was also inclined at a small angle to the vertical, so that the electron beam was incident at a small glancing angle

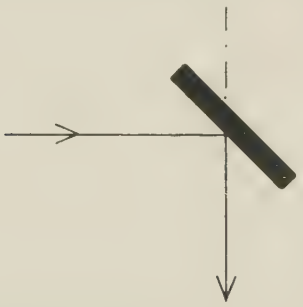

Fig. 11.—Disposition of Specimen and Electron Beam in Reflection Electron Microscope with High-Angle Scattering. (*Ruska and Müller.*[21])

and the image was formed by electrons scattered at a small angle in the direction of the axis of the objective and projector lenses (Fig. 12).

Von Borries succeeded in obtaining images showing a resolution of the order of 500 Å. with this system, although in his instrument the size of specimen which could be accommodated and the possibilities of manipulating it and performing experiments upon it *in situ* were rather restricted. In recent years there has been a renewed interest in the possibilities of this method, and a number of new developments have been reported. Kushnir, Biberman, and Levkin,[23] Haine and Hirst,[24] and the present author[25] have described modifications of standard instruments, and Fert[26] and Cosslett and Jones[27, 28] have described instruments developed especially for reflection microscopy.

The author's own work with this technique has been carried out with the Metropolitan-Vickers EM3 instrument. It was

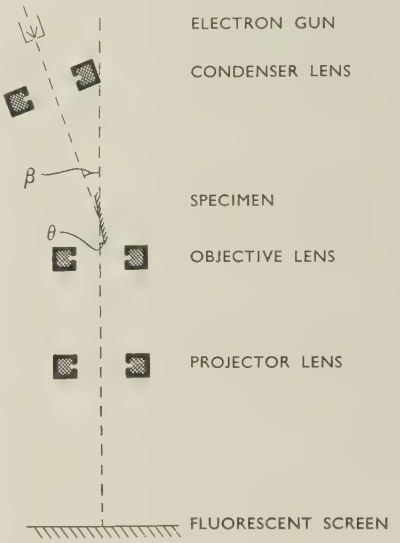

Fig. 12.—Schematic Section of Reflection Electron Microscope with Low-Angle Scattering. (*Von Borries.*[22])

first converted for reflection after the manner of von Borries by inclining the illumination at a fixed angle of 8° to the axis of the instrument. The microscope has since been made fully universal, with the help of Dr. J. S. Courtney-Pratt, by the construction of a new specimen chamber with five independent movements for the specimen and an adjustable illuminating system which may be inclined at any angle up to 12° from the vertical.

The image formed with the reflection microscope has a characteristic appearance arising from the small angle of observation (this is the angle of inclination of the specimen surface to the axis of the microscope, θ). It is convenient to define two magnifications, m_1, in a direction perpendicular to the plane of incidence, and m_2 in a direction in the plane of incidence.

Then $$m_2 = m_1 \sin \theta.$$

The geometry of the image is illustrated in Fig. 13 by a reflection micrograph of a square copper grid.

The grid bars perpendicular to the plane of incidence are, in reality, equal in width to those parallel to the plane of incidence. They appear narrower in the micrograph on account of the oblique angle of observation.

The resolution (δ) achievable with this system in the direction of maximum magnification is given approximately by an expression of the form:

$$\delta = \alpha \frac{f \Delta V}{V}$$

where α is the semi-angular aperture of the scattered beam included by the aperture in the objective lens, f is the focal length of the objective lens, V the accelerating voltage, and ΔV

the mean energy loss of the electrons in scattering from the surface. In practice, with the EM3, a value of 200–400 Å. is obtained for δ. There are possibilities of improving upon this when certain technical difficulties can be overcome.

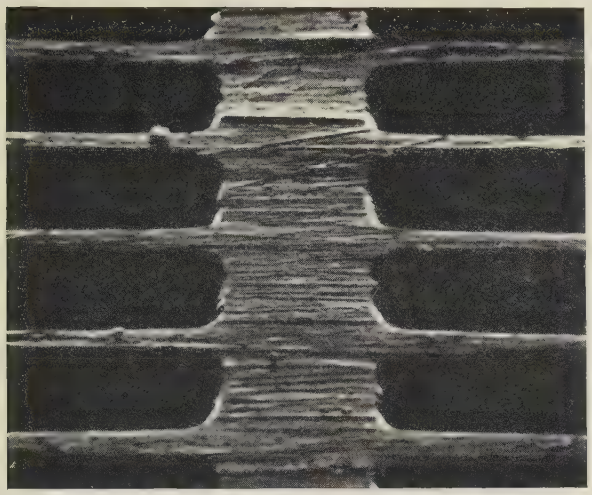

Fig. 13.—Reflection Electron Micrograph of Square Grid (200 t.p.i.). Angle of illumination (β–θ) 4°; angle of observation (θ) 4°.

Contrast in the image arises mainly from shadows cast by asperities which absorb the electron beam and from changes in slope of the illuminated surface. The lengths of shadows may be used to measure the heights of surface features, and on account of the high shadow contrast given by a sharp edge, it is possible to detect such a feature having a step height of the order of 30 Å.

It will be apparent that the use of the glancing-incidence reflection microscope in the field of constitutional metallurgy is limited to the study of those constitutional changes which become manifest as changes in the geometrical configuration of the surface. Thus, precipitated phases may be studied on an etched surface, as shown in Fig. 14, which is a micrograph of an etched pearlitic structure.

Such studies have a limited value in that most of the information contained in the micrograph may be obtained almost as readily with a Formvar replica. In favour of the reflection method it should be said, however, that it may permit the elimination of ambiguities in interpretation sometimes experienced with replicas. Furthermore, by using a small angle of inclination of the illuminating system, it is possible to obtain a reflection-diffraction pattern from a small selected area of the specimen, the electron-optical image of which is also recorded. This method should prove useful in providing complementary evidence on the location of the diffracting regions on a surface, when the reflection-diffraction method is used in constitutional studies. As pointed out by Haine and Hirst, when using small angles of inclination of the illuminating beam, additional contrast effects arise in the image as a result of Bragg (elastic) reflection from the crystal lattice of the surface layers. Thus, if a particular part of the crystal lattice happens to be in the correct orientation to cause a diffracted beam to pass through the objective aperture, the intensity of the image from this part of the surface is considerably enhanced. There is thus a detailed correspondence between diffraction pattern and reflection image which should yield useful information concerning the phase structure of a surface. It should, perhaps, be noted in passing that the diffraction pattern can be readily observed for only a short time because of the deposition of a layer of carbonaceous contamination on the surface as a result of the bombardment by the electron beam (see Ennos [29]).

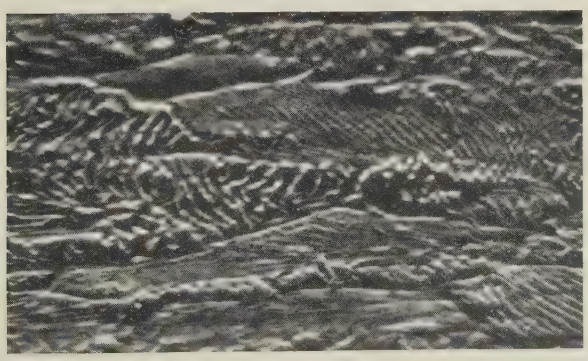

Fig. 14.—Reflection Electron Micrograph of Etched Pearlitic Steel. × 7000. (Reduced by one-half in reproduction.)

A second source of contrast in the image which may be used in constitutional studies is that due to changes in slope in the surface. It is well known that some phase transformations are associated with shear in the material leading to a change in the slope of the surface, as, for example, in the formation of martensite. The sensitivity of the technique for such studies is shown in micrographs of twins with their associated accommodation kinks on the cleavage face of zinc single crystals. The slope of the twin with respect to the cleavage face is 3° 58′ and that of the accommodation kink about 45′ (Moore [30]). These changes of slope are readily observable (see Fig. 15), and indeed it has even been possible to find fine structure within the accommodation kink corresponding to changes of slope of only a few minutes of arc (Moore [31]).

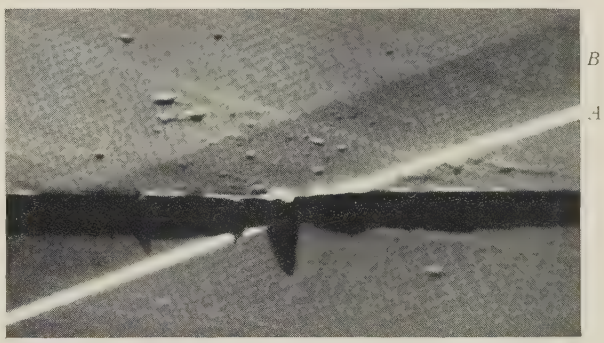

Fig. 15.—Reflection Electron Micrograph of Twin (*A*) and Accommodation Kink (*B*) Crossing a Large Cleavage Step on Cleavage Surface of Zinc Single Crystal. × 3000.

With a suitably designed objective lens, such that the specimen clears the pole-pieces, this technique provides considerable scope in the type of experiment that may be performed. Thus, it should be possible to undertake experiments in which the specimen is heated or deformed and kept continuously under observation. The first development in this direction has been made by Jones,[32] who has constructed a furnace which permits the heating of the specimen to 1000° C. with no deleterious effects upon the functioning of the instrument.

Although they are not essentially electron-microscopic methods, brief mention should be made, in conclusion, of two recent developments using electron-optical principles which should prove valuable in constitutional metallurgy.

X-Ray Shadow Microscope

In this instrument, in the form recently developed by Cosslett and Nixon,[33] a very small source of X-rays is obtained by causing the highly demagnified image of an electron source to fall upon a thin tungsten window which forms part of the vacuum wall of the instrument. If a thin solid specimen is now placed close to the X-ray source, an enlarged shadow image of the specimen will be thrown upon a photographic plate placed some distance from the source. Contrast in the image arises from differential absorption in different chemical components of the specimen, so that in effect a microradiograph of the specimen is obtained. The resolution depends upon the size of the electron spot. Cosslett and Nixon report a value better than 0·5 μ obtained experimentally and suggest that 100 Å. may ultimately be achieved with various improvements in the method.

Electron-Beam Microanalyser

Castaing [34] has recently constructed an instrument in which a very small-diameter electron beam is caused to impinge upon the surface of a specimen, and, by analysing in a spectrograph the characteristic X-rays emitted as a result of this electron bombardment, it is possible to identify the relative quantities of various elements present within the region under bombardment. This region may be localized to within 1 μ, the resolution being limited by the spreading of the electron beam within the specimen. A region of the specimen may be scanned by traversing it under the beam and recording the X-ray output continuously with a counter. The method obviously opens up completely new fields of investigation in constitutional metallurgy. Among the examples Castaing has chosen to demonstrate its value are the study of diffusion at a copper/zinc boundary and the analysis of the Al_2Cu phase precipitated as small particles in an aluminium–copper alloy. In the latter example, accurate quantitative analysis of the particles was possible down to a size of 3 μ. Below this size, only qualitative information was obtainable, on account of the diffusion of the electron beam beyond the limits of the particle.

It is also possible with this apparatus to carry out an examination of the crystallographic structure of a specimen on a very small scale by recording Kossel lines and extinction lines arising from the Bragg reflection of the X-rays formed within the specimen. Castaing has shown that, in this way, it is possible to determine the crystallographic structure of regions of the order of 10 μ in dia.

Conclusions

This survey indicates that there is a considerable diversity of electron-optical techniques of value in constitutional metallurgy. No single one by itself is universally applicable, and the choice of method must depend very much on the nature of the problem to be solved.

The resolution of most of the methods discussed, except for transmission and field-emission microscopy, is not strikingly superior to the best optical methods. Although there are possibilities of improving on the resolution in some cases, the real advantages of the methods lie in other directions. For example, those methods in which the specimen may be heated overcome the difficulties associated with observation of hot specimens in the optical microscope. Again, using electron diffraction, it is possible to determine the crystallographic nature, and hence the chemical identity, of the constituents of the surface. The value of electron diffraction is considerably enhanced when used in combination with electron-microscopic methods, either in transmission or reflection (see Williams,[35] Menter [36]).

As the metallurgist becomes more familiar with the electron optical techniques available to him, it cannot be doubted that there will be important advances in his knowledge of the constitution and structure of metals and alloys.

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AUTOMATIC RECORDING OF DILATOMETER MEASUREMENTS

By F. G. HAYNES,* M.Eng.

Introduction

In studying phase changes in metals by dilatometric methods, it is usual to measure the change in length of the specimen rather than the true change in volume, because of the experimental difficulties associated with volumetric work at high temperatures. For this reason, the methods of automatic recording to be described are concerned only with changes of length, and it is useful to consider first the essential requirements. These may be listed as follows: (1) adequate magnification, bearing in mind the small movements which may be significant; (2) accuracy, and freedom from zero drift; (3) minimum mechanical loading of the specimen, to avoid plastic deformation at high temperatures; (4) adequate speed of response; (5) availability of the recorded result as soon as possible after a given test is completed.

It is evident from the literature that there are many approaches to the problem, and it will not be possible here to do justice to the variety of ingenious methods which have been used. The methods have therefore been classified under three headings, namely: (1) Optical, (2) Mechanical, and (3) Electrical. Some of the methods inevitably fall under more than one of these groups, as will be seen.

Optical Methods

In the optical method, a beam of light is reflected from a mirror attached to the push-rod of the dilatometer, and magnifies the change in length of the specimen so that it can be read on a scale or recorded on a photographic plate. This method was used by Bain [1] in his original work on the isothermal transformation in steel, and enables virtually unlimited magnification to be obtained without imposing any significant load on the specimen. A commercial instrument embodying this principle was available at one time, made by Leitz, and the adaptation of it for isothermal-transformation work has been described by Andersen.[2]

However, in some cases, it is a disadvantage that no indications are visible during a run, and that the plate or film must be processed at the end of the run before the results can be seen. A further difficulty is sometimes encountered in the production of a reasonable trace on the photographic plate at widely differing speeds.

A novel optical arrangement has been described by Liebermann and Crandall,[3] in which a grating attached to the dilatometer push-rod moves past a fixed grating and so varies the intensity of a light beam shining through the two gratings. The lines and spaces in the gratings are of equal width, and a variation from 0 to 50% transmission is therefore obtained for a movement of one-half of one line spacing. The transmitted light falls on a photocell, and the output of this cell is amplified and used to operate an electronic recorder.

Mechanical Methods

The use of dial-gauges is well known for direct-reading dilatometers, and gives good results, provided that care is taken to prevent sticking and backlash. The loading imposed on the specimen is usually no more than 100 g., and with steel specimens this appears to be acceptable even at high temperatures.

For automatic recording a cine-camera may be used to photograph the dial at set intervals, and there are numerous examples of this technique.[4, 5] This method, however, has the drawback that the film must be processed, and the readings taken off it and plotted, before the results can be examined. Its main application, therefore, is where a short-term investigation is contemplated which does not justify more elaborate equipment, or alternatively where sufficient work is in hand to enable the processing and reading of films to be organized on a routine basis.

As far as is known, direct mechanical magnification has been used in only one case to move a pen across a chart, and, although a substantial specimen was used, the magnification was limited to 100 : 1, presumably because of the load imposed on the specimen by the friction in the system.

A method has been developed by Duwez and Martens [6] in which a light "finger" is coupled to the dilatometer push-rod and to a fine-pitch, feed-back screw. When a change in length occurs, the movement of the finger is detected by a mechanism similar to that used in self-balancing galvanometer-type recorders, and this mechanism rotates the feed-back screw until the finger resumes its normal position. The system is thus a null-balance mechanical servo, and the rotation of the feed-back screw is a direct measure of the push-rod movement. In practice the feed-back screw is coupled to a potentiometer, so that an e.m.f. proportional to the change in length is obtained.

Electrical Methods

Of the purely electrical methods, perhaps the best-known example is the parallel-plate condenser apparatus, as used by Stanton,[7] in which the change in length of the specimen alters the separation of the two parallel plates of a condenser that forms part of a tuned circuit, and the resultant change in current is amplified and used to operate a recorder. This method is capable of very high sensitivity—in the case mentioned, as high as 10,000 : 1—and with care the amount of zero drift can be made negligible, but the calibration is linear only over very small ranges, e.g. 0·06 mm. with a magnification of 1300 : 1. Other electrical methods employ the change of mutual inductance of two coils by moving one relative to the other, or moving an iron core within one or two coils. The work of Ewles and Curry [8] is an example of the mutual-inductance technique applied to rapid-displacement measurements, the results being displayed on a cathode-ray oscillograph.

Recording Length Against Temperature

So far, all the methods that have been described have been primarily concerned with recording length as such, and it is useful at this stage to consider the more general problem of recording length against temperature. With the simple optical method this has been done in one case by using the ex-

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pansion of a non-transforming specimen, adjacent to the test specimen, as a measure of the temperature. This has the disadvantage that the latent heat of transformation will cause a temperature difference between the two specimens, and the alternative method of using a thermocouple attached to the specimen is to be preferred. The thermocouple is connected to a mirror galvanometer incorporated in the optical system, and in this way a direct record is obtained of expansion against temperature.

With cine-camera recording, no special difficulties arise, since instruments are readily available for indicating thermocouple e.m.f.s, and it is a simple matter to photograph such an instrument beside the dial gauge.

Kingston [9] has reported a novel method of recording, using a dial gauge with an electrical "follow up" mechanism. This consists essentially of a motor-driven member concentric with the dial-gauge spindle, carrying contacts which can touch either side of the pointer. These contacts are set initially with a small clearance, but as soon as the pointer moves, one or other contact is made and energizes the motor through a relay, driving the contact assembly round in the appropriate direction until both contacts are again broken. The contact assembly thus "follows up" the movement of the dial-gauge pointer. This "follow up" is made to rotate the chart drum of an ordinary temperature recorder connected to a thermocouple in the specimen, and the desired expansion/temperature record is thereby obtained.

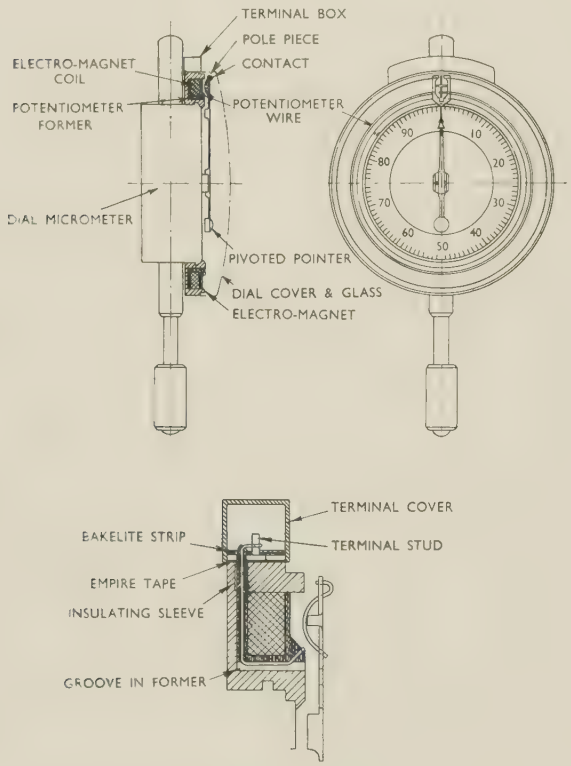

Fig. 1.—Construction of Remote-Reading Dial Micrometer.

Apparatus for Expansion/Temperature Recording

The method used by the author [10] is similarly based on the use of a dial gauge, but an electrical signal is obtained which can be readily recorded. The arrangement is shown in Fig. 1. A single-turn potentiometer wire is mounted on a Perspex former concentric with the scale, and can be touched by a contact mounted on the end of the pointer. The annular body of

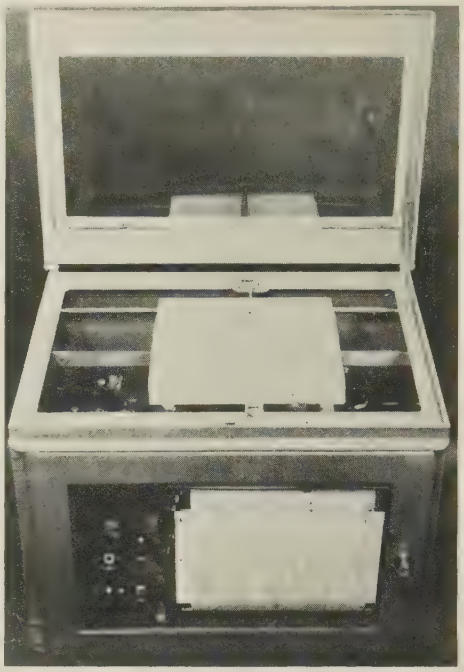

Fig. 2.—General View of Expansion/Temperature Recorder.

the device is made an electromagnet, and this can attract a soft-iron pole-piece on the pointer and so cause it to deflect until the contact touches the potentiometer wire.

The electromagnet is energized periodically in synchronism with the cyclic self-balancing of a potentiometric recorder, and in this way a virtually continuous record is obtained without restricting the movement of the dial-gauge pointer. The potentiometer wire is connected to the circuit of the recorder so that it forms part of a Wheatstone bridge, and there is therefore no risk of zero drift unless a change of resistance ratio occurs. Suitable ganged potentiometers are provided for adjustment of range and zero, and one revolution of the dial-gauge pointer, representing 0·010 in. change in length, can be made equal to the full-scale deflection of 10 in. There is thus a magnification of 1000 : 1, and the sensitivity is of the order of 0·1% of full scale.

The advantage of this method of recording is that the dial-gauge unit is portable, so that in work on the isothermal transformation in steel the dilatometer can readily be transferred from the austenitizing furnace to the quenching bath, and the actual dial reading can be seen at all times as well as the record. The calibration is linear, and under normal room-temperature conditions no drift can occur. Its principal drawback, apart from the rather delicate construction of the pointer, is the slow speed of response caused by the intermittent operation, and for that reason the dial-gauge readings are recorded manually for the first 25 sec. after quenching. This can be done very conveniently by noting the reading each time the pointer deflects, thus getting a series of readings timed accurately at 2-sec. intervals (this being the cyclic period of the self-balancing recorder).

For applications requiring an expansion/temperature record,

two recording potentiometers have been coupled together, the one operating in conjunction with the special dial gauge described and the other measuring the e.m.f. of a thermocouple attached to the specimen. The arrangement is shown in Figs. 2 and 3. A horizontal chart table is moved to and fro by the length-measuring potentiometer, and is crossed by a pen moved by the temperature-measuring potentiometer, so that the required expansion/temperature record is obtained. In addition, one of the strip-chart mechanisms of the original recorders has been retained, and this provides a record of temperature or expansion against time, as required. In some cases it is convenient to change over from temperature/time to length/time recording in the middle of a run, and this can be done readily without disturbing the record.

A typical record obtained with this apparatus is shown in Fig. 4.

The specimen used was 4 in. long and was heated at 8° C./min. to the austenitizing temperature and subsequently furnace-cooled. It will be noted that in this case the length-axis is equal to 0·050 in. expansion of the specimen, which is appropriate for the length of specimen used. For certain investigations shorter specimens have been used, and the full-scale deflection is then made equal to 0·010 in. as given above for simple expansion/time recording.

A further point of interest is that the temperature scale is linear, and the record can therefore be drawn on ordinary graph paper. Now commercial recording potentiometers usually have a linear millivolt scale, and use specially calibrated paper to suit the temperature/e.m.f. characteristics of a particular type of thermocouple. In the present case, Chromel/Alumel thermocouples are used, so that the departure from linearity is small, and this is corrected by moving the potentiometer contact (which is normally fixed) with a suitable cam mounted on the potentiometer spindle. The arrangement may be seen on the left-hand potentiometer in Fig. 3.

It is apparent then that this instrument enables direct temperature/expansion records to be obtained with both axes linear, which facilitates measurements of coefficient of expansion and in particular the recognition of small amounts of phase change.

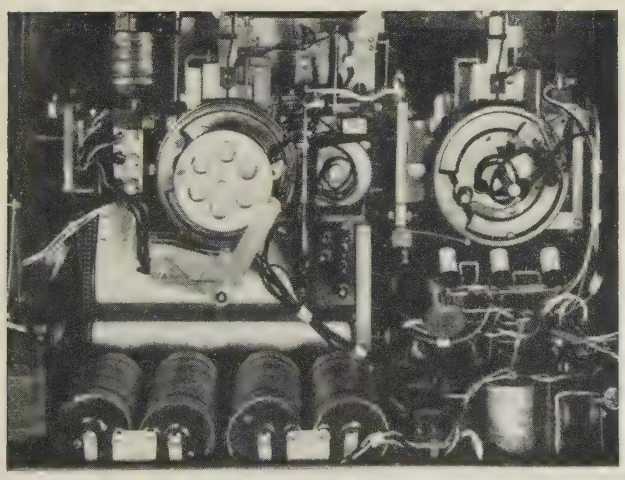

Fig. 3.—Close-Up View of Expansion/Temperature Recorder.

Before leaving the subject of temperature/expansion recording, it is worth noting that electronic self-balancing potentiometers are now available in America with two separate axes combined to give an " X/Y " record, and these are known generally as function plotters. Only one commercial instrument of this type is known to exist in this country, but it is expected that electronic function plotters will be available in due course with response times of the order of 5 sec. full scale. Provided a suitable input unit is chosen to convert change of length to change of voltage, such recorders can obviously be very valuable in determining temperature/expansion curves for very high rates of heating and cooling.

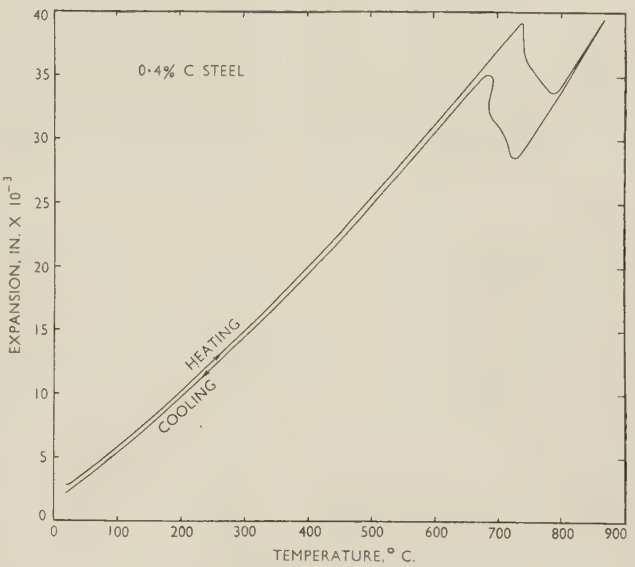

Fig. 4.—Typical Expansion/Temperature Record for Plain Carbon Steel.

Although the descriptions given above are necessarily far from complete, it is perhaps worth considering the specific problem of recording the isothermal transformation in steels, with particular reference to the rates of change recorded. Because of the nature of the isothermal transformation, the rate of change decreases with time, and it is usual to plot isothermal-transformation curves on a logarithmic time scale for this reason.

Recording with a Log Time Base

In the automatic recording of such data, a constant chart speed has the obvious disadvantage that if a sufficiently high speed is used to record the start of transformation accurately, the total length of the record may be considerable, leading to difficulties in measurement and storage. It is therefore desirable to record directly on a logarithmic time base, so that constant relative accuracy can be obtained with a compact record. This presents certain experimental difficulties because of the high ratio of chart speeds at the beginning and end of the record. In the case to be described, the time scale is from 25 to 100,000 sec., and if this is covered logarithmically the velocity ratio becomes 4000 : 1. This precludes the use of the usual differentiating mechanisms, and has led to a discontinuous type of drive, in which the chart is moved in a series of equal steps at progressively increasing intervals of time. A device resembling a gramophone is used to produce electrical pulses at the desired logarithmically spaced intervals, and this controls the operation of an electromagnetic ratchet motor which moves the chart $\frac{1}{20}$ in. per pulse.

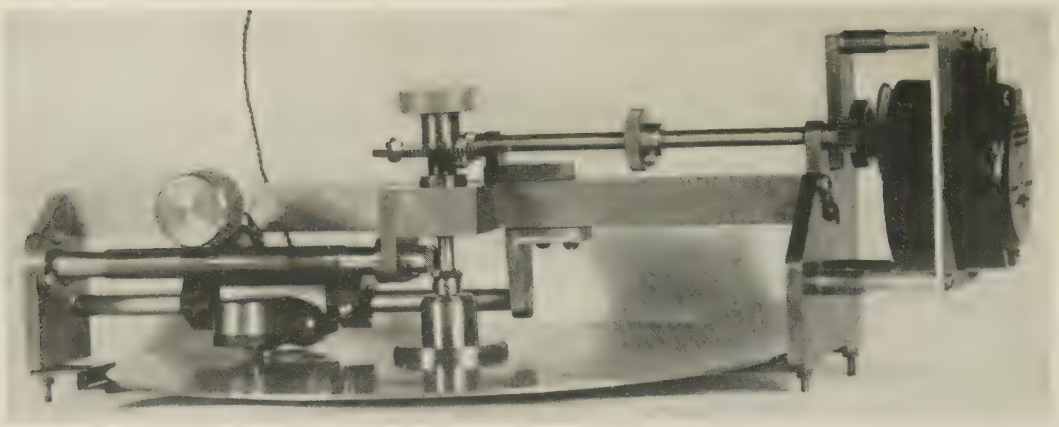

FIG. 5.—Logarithmic Pulse-Generating Mechanism.

The " gramophone " consists of a steel disc with a series of small holes spaced logarithmically in a spiral, and a " pick-up " unit which is traversed radially inwards as the record disc revolves. The arrangement is shown in Fig. 5.

FIG. 6.—Typical Isothermal Transformation Record on Logarithmic Time Scale.

A series of 180 pulses is obtained, covering the period from 25 to 100,000 sec., and this corresponds to a chart length of 9 in. A typical record is shown in Fig. 6. It will be apparent that by changing the speed of rotation of the gramophone disc, the total time covered may be altered while retaining the logarithmic characteristic, and this has been done for certain steels, using a time scale of 100 to 400,000 sec.

It is hoped that this brief account of the automatic recording of dilatometer measurements has helped to show the diversity of methods which have been, and are being, used and that for any single application there is no one ideal method, the choice of technique depending very largely on the individual investigator.

Acknowledgements

The author wishes to thank Mr. M. B. Coyle, M.A., for his invaluable collaboration in the design and construction of the temperature/expansion recorder, and for suggestions leading to the development of the logarithmic time base. This latter equipment was designed and constructed with the assistance of Mr. P. H. Dawson, B.Sc., to whom the author is indebted for many valuable suggestions.

Thanks are also due to Dr. Willis Jackson, F.R.S., M.I.E.E., Director of Research and Education, and to Mr. B. G. Churcher, M.Sc., M.I.E.E., Manager of the Research Department, Metropolitan-Vickers Electrical Co., Ltd., for permission to publish this paper.

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CONTINUOUS-COOLING TRANSFORMATIONS IN STEELS

By G. MAYER,* B.Sc., A.I.M.

Introduction

THE constitutional changes which occur in ferritic steels, when cooled from the austenitic condition, have been studied largely by use of the well-known isothermal technique. The data derived from these studies have provided the foundation for modern steel selection and heat-treatment, but the application of the data has been mainly indirect, since industrial practice usually involves continuous cooling rather than isothermal treatment.

Several attempts have been made to determine transformations under continuous-cooling conditions in order to provide diagrams which could be used more directly, and the researches of Liedholm,[1] Manning and Lorig,[2] and Grange and Kiefer[3] should be mentioned in this connection.

My colleagues and I have recently developed a technique for measuring the transformations in steels when cooled at finite rates,[4, 5] and our approach to the problem was made with three definite aims: (1) to employ cooling rates typical of industrial quenching practice; (2) to measure, and to portray in the form of simple diagrams, various stages of transformations; and (3) to employ, if possible, a technique capable of fulfilling these conditions and yet sufficiently simple to permit the examination of a wide variety of steels within a reasonable time. It was decided to restrict the cooling rates employed to those of the centre, mid-radius, and near-surface positions of 1–6-in.-dia. bars quenched in oil, since these would include the majority of cooling rates used in industrial practice. This involved the direct measurement of the cooling rates of several oil-quenched bars at different cross-sectional positions. The next problem was to reproduce these cooling rates consistently in test-pieces of suitable form for the continuous measurement of transformation and temperature. It was also necessary that the cooling should be as nearly as possible uniform over the whole of the test-piece. It was found that these conditions could be satisfied by air-cooling cylindrical bars varying in diameter from 0·054 to 0·8 in., provided that the simulation of the oil-quenching rates was restricted to the temperature range 700°–300° C. Fortunately, for almost all the alloy engineering steels, the effect of cooling outside this temperature range on the sub-critical transformations is negligible. At temperatures above 700° C. the transformation rates are very low, and variations in cooling rate have little effect on the tendency to transform. Below 300° C., the transformation can be regarded as essentially martensitic, except for high-carbon steels with low M_s temperatures, and the detailed effects of cooling rate on the progress of this transformation with temperature are of little interest for practical purposes.

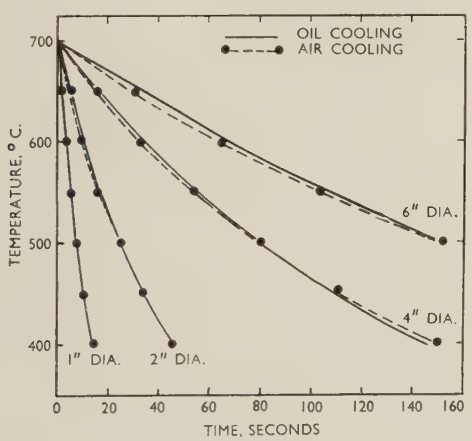

FIG. 1.—Comparison (at Temperatures below 700° C.) of the Oil-Cooling Curves for the Axes of 1–6-in.-dia. Bars with the Air-Cooling Curves of Bars of "Equivalent" Size.

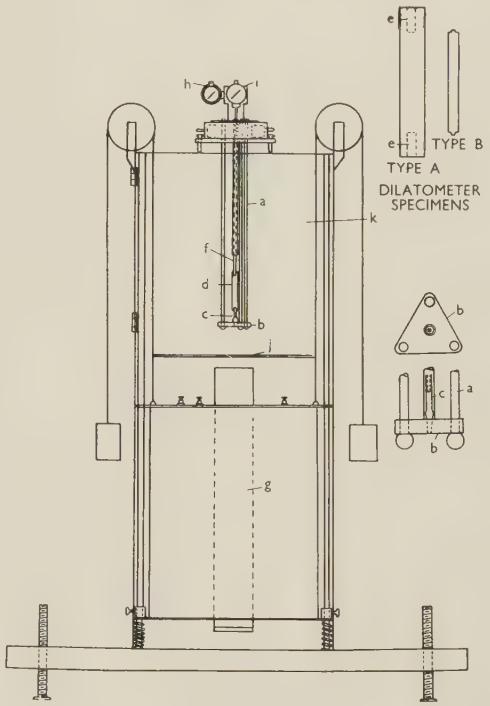

FIG. 2.—Dilatometric Apparatus, with Types of Dilatometer Specimen.

The cooling curves shown in Fig. 1 illustrate the closeness with which bars cooled in air simulate the cooling of bars quenched in oil over the sub-critical temperature range. The oil-cooling curves were determined by direct experiment, and the air-cooling curves were derived by interpolation of experimental data obtained on a range of bar sizes. It was not possible to derive interpolated data at temperatures below 400° C., owing to the interfering effects of transformation in the steels, but the general trend of the curves suggests that close matching may be expected down to at least 300° C.

The simulation of oil-quenching rates by air-cooling relatively small bars made it possible to measure the progress of transformation with decreasing temperature by means of the dilatation change accompanying transformation. A special dilatometer was designed for the test-pieces of various diameters, which permitted them to cool freely in air after

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austenitizing at appropriate temperatures. The dilatometer, austenitizing furnace, and air-cooling chamber are illustrated in Fig. 2.

Description of Dilatometer

The dilatometer consists of a silica plate (*b*) supported by three silica rods (*a*) which are cemented by plaster of Paris into a water-cooled Invar head, which also carries a dial-gauge (*i*) reading to $\frac{1}{10000}$ in. The silica base plate has a tapered hole into which fits a tapered plug (*c*) supporting the specimen (*d*). The upper end of the specimen is held by a silica tube (*f*) which transmits the length changes of the specimen to the dial-gauge. The specimen and tube assembly is under light compression provided by the spring of the dial-gauge. Two types of test-piece are employed, as shown in Fig. 2. Those greater than $\frac{1}{4}$ in. in dia. are drilled at the ends to a depth equal to the specimen diameter, and the silica plug and transmission tube fit into these flat-bottomed holes (*e*). The ends of the specimens cool at slightly faster rates than the remainder of their lengths, but with this shape of test-piece the end-portions so affected are not included in the test-length, which is usually 2 or 3 in. A similar provision could not be made for the specimens less than $\frac{1}{4}$ in. in dia., and these have a small spigot machined at each end which engages in the holes in the silica plug and transmission tube. In these smaller samples, however, the diameters of the silica plug and tube approach that of the specimen, and end-cooling is retarded by the slower cooling of the silica tubes. The portion of the test-length affected is small, however, and tests conducted to determine the magnitude of the error likely to be introduced failed to detect any significant effect.

The specimens are coated with a thin layer of electro-deposited nickel (0·0015–0·002 in. thick) to avoid scaling and decarburization during austenitizing and cooling. Austenitizing is effected by raising the counter-balanced furnace (*g*) to enclose the dilatometer and specimen. The temperature of the specimen is registered by means of a fine-wire platinum platinum–rhodium thermocouple spot-welded on to the surface of the specimen, the wires of the thermocouple being welded to separate points on the specimen about $\frac{1}{4}$ in. apart. The e.m.f. from the thermocouple deflects a taut-suspension moving-coil galvanometer which has a short time period, and a beam of light is reflected from the galvanometer mirror on to a calibrated temperature scale. The total resistance of the galvanometer circuit is made large (of the order of 1200 ohms) so that the small change in the resistance of the thermocouple during heating and cooling does not affect the calibration of the temperature scale. At the beginning and end of each austenitizing period the calibration is checked by first resetting the galvanometer zero e.m.f. reading and then applying to it a known e.m.f. from a potentiometer corresponding to a standard deflection on the temperature scale. A small resistance in the galvanometer circuit is then adjusted so that the standard deflection is obtained. Slight changes in the torque characteristics of the galvanometer suspension wire are thus corrected for each experiment. After austenitizing and checking the temperature scale calibration the thermocouple is switched into the galvanometer circuit again and the furnace is lowered fairly quickly. A baffle plate (*j*) is then pushed between the furnace and dilatometer, thus allowing the specimen to cool in still air in the enclosed chamber (*k*). During cooling the temperature change is registered by the movement of the illuminated cross-wires along the temperature scale and at pre-selected temperatures a button is pressed by the operator which electrically operates a 35-mm. camera, thus recording the dial-gauge readings. A stop-watch (*h*) placed beside the dial-gauge is also photographed and provides a time/temperature record which is used to check the cooling rate against the predetermined standard rate for each size of test-piece. Dilatation/temperature curves are then plotted from the data recorded on the film.

Continuous-Cooling Transformation Curves

A typical dilatation curve is shown in Fig. 3 (*a*). The curves are linear down to the temperature at which transformation starts, and it is therefore quite easy to determine this temperature. To determine the further stages of transformation from the curves, it is necessary to superimpose a second curve on them, representing the dilatation of the steel in the fully transformed or ferritic condition. This curve is

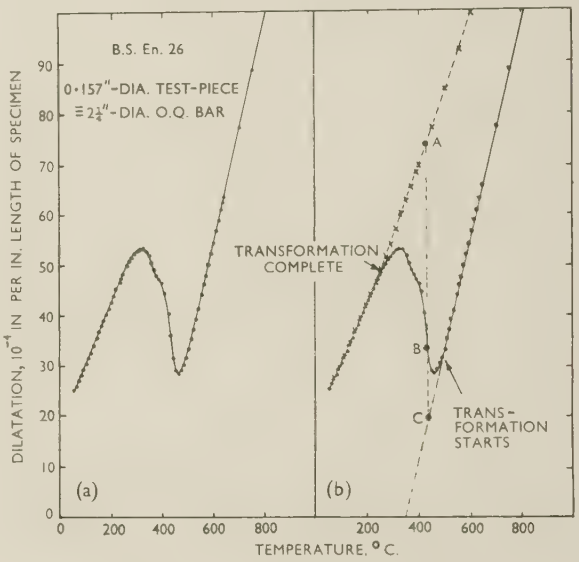

Fig. 3.—Typical Dilatation Curves.

obtained by a separate experiment in which a 0·1-in.-dia. specimen is heated to just below the Ac_1 change point and allowed to cool again. During cooling, dilatation and temperature are again recorded. The dilatation/temperature curve thus obtained will match those of any of the samples cooled from the austenitizing temperature for temperatures below those at which transformation of the austenitized samples to ferrite and carbide is complete. The curve for the steel in the fully ferritic condition is superimposed on the transformation curves therefore in such a way that matching of the two is obtained over a range of temperature. The distance between the upper curve and the extrapolation of the linear portion of the transformation curve now represents the dilatation which the austenitic samples would undergo for complete transformation at any temperature, and the amount of transformation corresponding to any point *B* on the curve is given, therefore, by the ratio of the lengths *BC*/*AC* (Fig. 3 (*b*)). In practice the temperatures for 0, 10, 50, 75, 90, and 100% transformation are determined for each size of test-bar, and these data for a range of bar sizes are plotted as a transformation diagram of the type shown in Figs. 4 and 5.

In these diagrams the diameters of the air-cooled bars used for the experiments are converted to the known equivalent diameters of oil-quenched bars, and several scales are used to represent different positions across the sections of the oil-

quenched bars ($r/b = 0$, 0·5, and 0·8, where r = distance from bar axis, and b = radius of bar). Temperature is shown on the ordinate scale, and the lines of the diagram indicate the various stages of transformation For any particular bar diameter and section position the temperature for each stage of transformation on oil-quenching is given by the intersection of the corresponding ordinate and transformation line (Fig. 4). The diagrams are discontinued below the M_s temperature of the steel, since, as mentioned previously, below this temperature the transformation of any remaining austenite may be regarded as essentially martensitic.

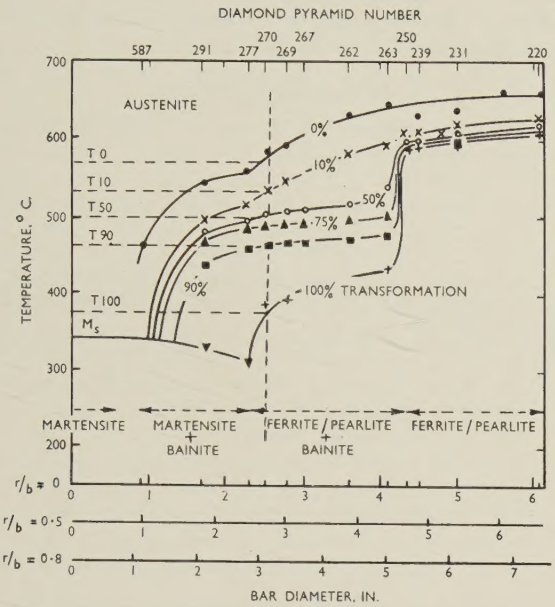

FIG. 4.—Continuous-Cooling Transformation Diagram for Oil-Quenched Bars of a B.S. En 111 Steel Austenitized at 845° C.

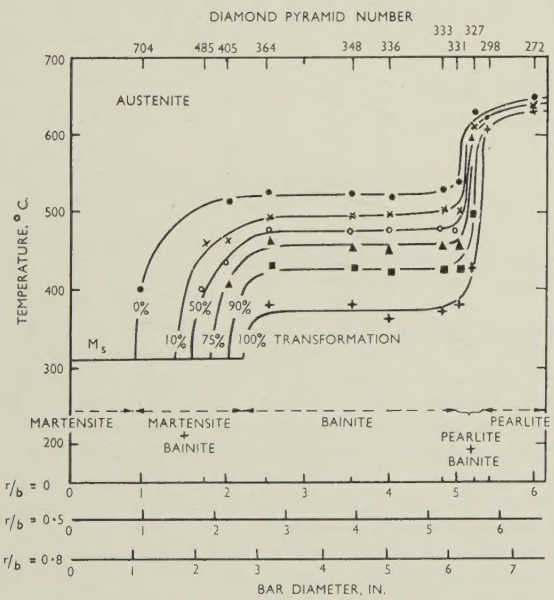

FIG. 5.—Continuous-Cooling Transformation Diagram for Oil-Quenched Bars of a B.S. En 18 Steel Austenitized at 860° C.

The type of continuous-cooling diagram shown is felt to be of direct practical value, since from it the following information can readily be obtained :

(1) The limiting diameter above which a steel cannot be fully hardened.

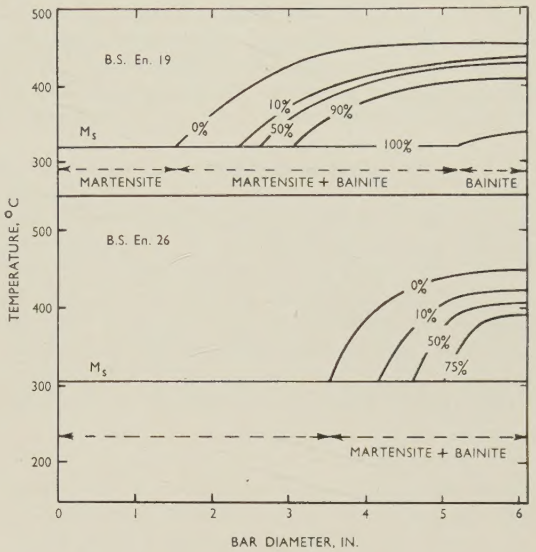

FIG. 6.—Continuous-Cooling Transformation Diagrams for Oil-Quenched Bars of B.S. En 19 and 26 Steels.

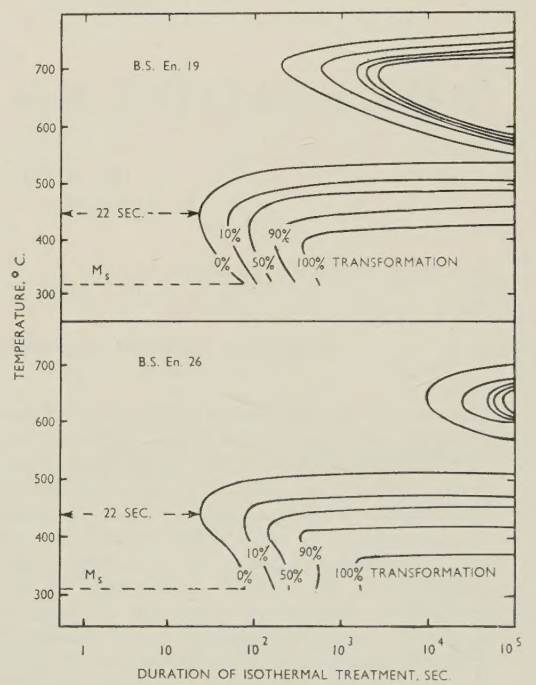

FIG. 7.—Isothermal Transformation Diagrams for B.S. En 19 and 26 Steels.

(2) The size ranges in which transformation is essentially bainitic or pearlitic or results in a mixture of these constituents. The temperature ranges in which the various constituents are formed are also indicated.

(3) The as-quenched hardness values at various positions in the oil-quenched bars. These are recorded along the top

edge of each diagram and are determined on the air-cooled dilatometer samples after test.

To both the research metallurgist and those controlling industrial heat-treatment, the diagrams offer a further advantage compared with isothermal transformation diagrams. From the data which we have so far obtained it appears that some steels may have substantially different hardenabilities which are revealed by the continuous-cooling diagrams, but which are reflected as only minor differences in the corresponding isothermal diagrams. An example of this is shown by the diagrams in Figs. 6 and 7, for an En 19 and an En 26 steel.

The continuous-cooling diagrams (Fig. 6) show a large difference in the critical diameters for full hardening by oil-quenching, but the bainite regions of the isothermal diagrams (Fig. 7) are almost identical, and since transformation to bainite occurs when these steels are incompletely hardened, it might be expected from the isothermal data that the two steels would have similar critical diameters for full hardening. This illustration provides a striking demonstration of the advantages to be gained from studies of continuous-cooling transformations.

At the present stage of development of the technique described for continuous-cooling transformation studies, the data obtained are limited to intermediate cooling rates. The measurement of transformation at high cooling rates is particularly desirable, however, in many steels. In addition, transformation data for other quenching media would be useful. These limitations are not insuperable, however, and at some future date no doubt further techniques will be developed to provide these data.

Acknowledgements

The author is indebted to The Mond Nickel Co., Ltd., for permission to publish this paper.

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This monograph deals with the application of thermodynamics to the quantitative study of metals and alloys. The fundamental theory of the subject is presented first, and is followed by some illustrative calculations on pure metals. Then the theory of solutions is developed and exemplified by calculations on solid and liquid alloys. Emphasis is laid on the usefulness of thermodynamics for the accurate correlation of various equilibrium properties. Attention is particularly directed to the information that can be deduced from phase boundaries. Detailed calculations are presented on some typical systems for which measurements of vapour pressures, electrode potentials and heats of mixing are available; these results are combined with a study of liquidus, solidus and solid-solubility curves to derive the activities of both components in the liquid and solid phases. It is shown how a free-energy equation for a system, deduced from a suitable set of accurate experimental measurements, furnishes a reliable basis for calculating other equilibrium properties. To assist in numerical calculations, tables of functions that continually recur in thermodynamic problems are provided.

Elementary statistical mechanics is introduced for calculating the entropy of gases and for interpreting the form of free-energy curves in solid and liquid alloys. A critical study is made of the extent to which liquid alloys behave as "regular solutions."

THE INSTITUTE OF METALS : 4 Grosvenor Gardens, London, S.W.1

OTHER NEWS

Society for Visiting Scientists

The attention of members is drawn to the Society for Visiting Scientists, Ltd. Established in the spring of 1944, the Society seeks to be a focus for all scientists visiting the United Kingdom, and to put them in touch with British scientists and with one another. The Society aims at providing and encouraging an active exchange of scientific thought and discussion between scientists of the United Kingdom and scientists from overseas.

The House of the Society, at 5 Old Burlington Street, London, W.1, provides a meeting place, a refectory, a bar, and some residential accommodation. In addition, an information service is provided, which is open to all visiting scientists; thus any scientist arriving in this country can, if he wishes, proceed at once to the House and be given such advice and information as is available. Scientists from all countries are welcomed by the Society, which tries to assist its visitors in every way possible.

Among the Society's activities is the holding of receptions in honour of groups of scientists visiting Britain, who thus have an opportunity of meeting at the House their British and oversea colleagues. Informal discussion meetings of general interest to scientists are organized. The Society also provides a forum for topics which are outside the scope of specialized scientific societies, but which are of importance to scientists as a whole.

The annual subscription is three guineas, with an entrance fee of one guinea. Oversea postgraduate students in science who hold research grants may become Student Associates, at an annual membership fee of one guinea; they pay no entrance fee. Other oversea members pay no annual subscription, but an entrance fee of five shillings.

Further particulars may be obtained from the Assistant Secretary, Society for Visiting Scientists, Ltd., 5 Old Burlington Street, London, W.1.

DIARY

Local Sections and Associated Societies

17 December. North East Metallurgical Society. "Some Aspects of Iron Production", by Dr. P. K. Gledhill. (Cleveland Scientific and Technical Institution, Middlesbrough, at 7.15 p.m.)

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4 January. Oxford Local Section. "Titanium", by Major P. Litherland Teed. (Cadena Café, Cornmarket Street, Oxford, at 7.0 p.m.)

5 January. South Wales Local Section. "Oxidation of Metals", by Dr. U. R. Evans. (Metallurgy Department, University College, Singleton Park, Swansea, at 6.45 p.m.)

6 January. Birmingham Local Section. A Debate on the motion "This House Considers that, at the Present Stage of Industrial Metallurgy, Empirical Methods of Research are more Profitable than those Employing the Fundamental Approach". Proposed and seconded by Dr. D. V. Atterton and Mr. J. Crowther. Opposed and seconded by Dr. A. R. E. Singer and Mr. G. Parkin. (James Watt Memorial Institute, Great Charles Street, Birmingham 3, at 6.30 p.m.)

6 January. London Local Section. "Some Aspects of Twinning and Kinking in Metals", by Professor A. H. Cottrell. (4 Grosvenor Gardens, London, S.W.1, at 6.30 p.m.)

12 January. Manchester Metallurgical Society. Conversazione. (Metallurgy Department, University of Manchester, at 6.30 p.m.)

13 January. Liverpool Metallurgical Society. Discussion on "Inspection *versus* Production". (Liverpool Engineering Society, 9 The Temple, Dale Street, Liverpool, at 7.0 p.m.)

Other Societies

15 December. Society of Chemical Industry, Corrosion Group. "Corrosion Prevention in the Telecommunications Industry", by C. E. Richards. (Chemical Society, Burlington House, Piccadilly, London, W.1, at 6.30 p.m.)

16 December. Institution of Mining and Metallurgy. General Meeting. (Geological Society, Burlington House, Piccadilly, London, W.1, at 5.0 p.m.)

17 December. Institution of Mechanical Engineers. Thomas Hawksley Lecture: "Recent Studies of Metallic Friction", by Dr. F. P. Bowden. (The Institution, 1 Birdcage Walk, London, S.W.1, at 5.30 p.m.)

17 December. West of Scotland Iron and Steel Institute. "Non-Destructive Testing of Metals", by J. M. Mowat. (39 Elmbank Crescent, Glasgow, C.2, at 6.45 p.m.)

31 December. Institution of Mechanical Engineers. "Development of the Lost-Wax Process of Precision Casting, 1949–1953", by J. S. Turnbull. (The Institution, 1 Birdcage Walk, London, S.W.1, at 5.30 p.m.)

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14 January. Institution of Mechanical Engineers. James Clayton Lecture: "The Theory of Plasticity: Recent Achievements and Future Problems", by William Prager. (The Institution, 1 Birdcage Walk, London, S.W.1, at 5.30 p.m.)

APPOINTMENTS VACANT

ENGLISH ELECTRIC CO., LTD. A post offering opportunities for progress in a comparatively new field of research exists at the Nelson Research Laboratories, Stafford, where a METALLURGIST is required for investigation on a large variety of materials, especially those used in high-vacuum work. This vacancy calls for adaptability on the part of the applicant in applying established techniques to new problems and an ability to devise fresh techniques for the same. An interest and some experience in metallographic preparation would be an advantage. Apply in confidence to Dept. C.P.S. 336/7, Strand, London, W.C.2, quoting Ref. 997D.

HADFIELDS, LTD., have a number of vacancies in their Research Department. The posts are concerned with Physical Metallurgy, High-Temperature Metallurgy, Mechanical Testing, and other research work of the widest scope. Applications are invited from: (1) Experienced graduates or equivalent. Senior positions concerned with the design of experiments and the interpretation of results. (2) Graduates or equivalent for general duties. Experience not essential. Written applications, stating whether for post (1) or (2), with details of experience, qualifications, training, &c., to Personnel Manager, Hadfields, Ltd., East Hecla Works, Vulcan Road, Sheffield 9.

METALLURGICAL ASSISTANT required with minimum qualification H.N.C. (Metallurgy) and must have completed National Service or not liable. Applicants should preferably have had experience of metallography of ferrous and non-ferrous metals, particularly in heat-treated steels. Write Joseph Lucas (G.T.E.), Ltd., Victor Works, Bowring Park Road, Liverpool 14.

METALLURGICAL CHEMIST. Competent young analyst with knowledge of ferrous and non-ferrous analysis and the use of modern techniques required by organization near Leicester. Excellent opportunity for carrying out interesting work connected with a variety of research and development projects. The position is permanent and progressive. Some knowledge of plating an advantage. Should have completed National Service. Superannuation scheme in operation. Send full details, including salary required, to Box No. 377, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

METALLURGIST, A.I.M. standard, required to assume responsibility for development of foundry processes. Experience with cobalt-base alloys an advantage. Good salary with excellent prospects. Apply Deloro Stellite, Ltd., Highlands Road, Shirley, Birmingham, marked " Confidential ".

METALLURGIST with experience in foundry technology of aluminium- and copper-base alloys. Applicants must be qualified to control experimental and production techniques in sand, gravity die, and shell-mould processes. Small company in south Birmingham area. Salary £950 per annum. Full details, experience, age, qualifications, &c., to Works Director, Diecastings, Ltd., Highgate Square, Birmingham 12.

METALS RESEARCH. The Mond Nickel Co., Ltd., has several vacancies in its Birmingham Laboratory for men with Honours Degrees in Metallurgy, Physics, Engineering, or Chemistry to work on projects associated with the development and application of (*a*) alloy steels, (*b*) cast irons, (*c*) powder metallurgy alloys, (*d*) high-temperature materials, and (*e*) corrosion-resistant materials. Previous works or laboratory experience desirable but not essential. Write stating age, qualifications, experience, salary required, &c., to Manager, Development and Research Dept., The Mond Nickel Co., Ltd., Sunderland House, Curzon St., London, W.1. Mark envelope " Confidential L.20 ".

RESEARCH METALLURGIST with good degree and experience is required by organization near Leicester to undertake work on problems associated with machining and forming of ferrous and non-ferrous materials. Knowledge of the cold working of metals would be an advantage. Surroundings are pleasant, and the successful candidate will be working in interesting fields which offer wide scope. Permanent progressive position. F.S.S.U. in operation. Full details, including age, experience, qualifications, and salary required, to Box No. 379, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

SENIOR METALLURGIST required for Works Laboratory. Candidates should have a good degree in Metallurgy and considerable experience in the investigation of factory problems. The work will be concerned with the Metallurgical problems involved in the manufacture of lamps and radio valves, including the production of tungsten and molybdenum. Some experience in powder metallurgy would be an advantage. Age 35–45 years. Apply in writing, giving full details, to the Works Personnel Officer, Mullard Blackburn Works, Ltd., Philips Rd., Blackburn. Please quote ref. M/13/L.

THE NEW SOUTH WALES UNIVERSITY OF TECHNOLOGY

VACANCY FOR ASSOCIATE PROFESSOR IN METALLURGY, NEWCASTLE UNIVERSITY COLLEGE, NEW SOUTH WALES, AUSTRALIA

The University invites applications for the vacant position of Associate Professor in Metallurgy, Newcastle University College. Salary £A1950 per annum.

Applicants must be graduates holding a degree in Science, Engineering, or Metallurgy, with post-graduate research and experience and preferably some industrial experience. The successful applicant will be required to initiate and lead research, and to administer the teaching activities at Newcastle, within the general educational programme of the School of Metallurgy, in the N.S.W. University of Technology.

Well-equipped laboratories, whose facilities are expanding, are available at Newcastle.

The appointee will be eligible, subject to medical examination, to contribute to the New South Wales Superannuation Fund, which will provide a pension of £A1014 per annum.

First-class shipping fares to Sydney of appointee and family will be paid.

The University reserves the right to fill the position by invitation.

Further particulars may be obtained from Professor R. Myers, Head of the School of Metallurgy, Kensington, Sydney.

Five copies of applications, with testimonials and other supporting documents should be lodged with the Agent General for New South Wales, 56/57 Strand, London, W.C.2, before 21 December 1954, also one copy of application should be forwarded by air mail to the Bursar, N.S.W. University of Technology, Broadway, New South Wales, Australia, by the same date.

THE UNIVERSITY OF SHEFFIELD

Applications are invited for the CHAIR OF PHYSICAL METALLURGY to be filled early in 1955. Salary not less than £2,000 a year, with F.S.S.U. provision and family allowance. Further particulars should be obtained from the Registrar, The University, Sheffield 10, to whom applications should be sent by 8 January 1955.

THE UNIVERSITY OF SHEFFIELD

Applications are invited for the T. I. RESEARCH FELLOWSHIP tenable in Department of Metallurgy. The object of the Fellowship is to advance knowledge in the field of Metallurgy; candidates should already have some research experience, but not necessarily in this field. Normal tenure will be five years, but the appointment will be for two years in the first instance and thereafter will be renewable annually. Stipend £750 per annum for the first year, rising by annual increments of £50 to £950 per annum, together with superannuation provision under the F.S.S.U. A higher stipend may be paid to an exceptional candidate. Applications (3 copies) including the names and addresses of referees and, if desired, copies of testimonials, should reach the Registrar (from whom further particulars may be obtained) not later than 15 December 1954.

A. W. CHAPMAN,
Registrar.